# THE PRINCIPLES

OF

# INSECT CONTROL

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# PREFACE

THE branch of Biological Science known generally as Economic Entomology has made enormous strides within the last ten or fifteen years. Its progress may be said to be an outcome of the greater attention that is being paid to Agricultural Science. Improved methods of transport have given the Agriculturist and Horticulturist a wider outlet for his produce, and the wheat fields of Manitoba and Illinois, the fruit orchards of California, Australia, and South Africa, the cattle ranches of Argentina and New Zealand, the cotton fields of Egypt and India, Uganda and Louisiana, have benefited accordingly. This wide distribution of food stuffs has brought about a corresponding increase in the range of injurious Insect pests, so that the adequate recognition of Economic Entomology and the scientific application of Insect Control measures are of increasing importance.

In no branch of human knowledge, perhaps, has a more extensive literature accumulated in a shorter period of time. The literature concerning Economic Entomology has, in fact, become unwieldy, consisting as it does, to a large extent, of short articles or brief notes scattered throughout a wide range of scientific and technical journals, inaccessible very often to the average scientific man, and, as often as not, published in an unfamiliar language. Short abstracts of many such articles are published monthly in the *Review of Applied Entomology*, the *Experimental Station Record*, and the *Monthly Bulletin of Agricultural Intelligence and Plant Diseases* (Rome), but no attempt has as yet been made to put forward a digest, a general résumé, of the progress of this branch of Science during the last twenty years.

Many excellent works dealing with Economic Entomology

have been published and continue to be published, but the primary aim of such works is the description of the insects themselves; methods of controlling such insect pests are invariably relegated to an appendix or to a preliminary chapter, comprising a few old recipes for home-made insecticides, a picture of a knapsack sprayer, possibly some information regarding parasite-introduction as typified by *Novius cardinalis*, and a few platitudes regarding clean cultivation. For any information concerning the chemical nature of insecticides, locust control, host immunity, status of birds, fumigation dosages, the comparative merits of dusting and spraying, to name just a few of the modern aspects of the subject, the inquirer will search in vain.

An accessible résumé of recent literature concerning Insect Control methods has been urgently needed for some time past, and this book is an effort to supply such a summary, within the limits determined by the publisher.

Such a compilation has necessitated the perusal of an enormous number of original papers, and we have been fortunate in having at our disposal the very excellent library facilities afforded by the Department of Agricultural Entomology of the University of Manchester. The *Review of Applied Entomology*, published by the Bureau of Entomology, London, has been invaluable, and we have freely availed ourselves of the abstracts published therein, particularly in cases where the original paper was inaccessible to us.

We recognise that considerable criticism can be levelled against the arrangement of the material, but it should be noted that this is the first attempt, so far as we know, to cover the whole field of Insect Control, and we have not been able, in consequence, to fall back upon any recognised method of arranging the vast accumulation of literary material.

To the Chiefs of Staff of our respective University Departments we are particularly indebted for the facilities afforded to enable us to attempt this publication, and we owe also a debt of gratitude to the Head of the United States Bureau of Entomology, Dr. L. O. Howard, and to the large number of American and Canadian entomologists, too numerous to mention individually, whose kindness made it possible for one of us to

gain an insight into the work of many of the United States and Canadian Agricultural Experimental Stations during the summer of 1921.

Our acknowledgements are due also to the following firms: To the Bean Spray Pump Co., Lancing, Michigan, U.S.A., for the loan of blocks of a Large Power Sprayer, Spray Booms, Bean Spray Gun; to the Cambridge University Press, London, England, for the loan of the blocks for Fig. 13; to the Deming Company, Salem, Ohio, U.S.A., for the loan of blocks of a Bucket Sprayer, Compressed Air Sprayer, Barrel Sprayer, Comet Spray Gun, Bordeaux, Simplex, and Vermorel types of Nozzle, and Medium Power Sprayer; to Messrs. Drake and Fletcher, Maidstone, England, for the loan of blocks of a Barrow Sprayer, Mystifier Adjustable Nozzle, and Seneca Nozzle; to the Field Force Pump Co., Elmira, N.Y., U.S.A., for permission to reproduce Fig. 21; to the Niagara Sprayer Co., Middleport, N.Y., U.S.A., for the loan of the block of a Power Duster; to the Springfield Dry Powder Sprayer Co., Tenn., U.S.A., for permission to reproduce Fig. 28; to Messrs. Vermorel, Villefranche, France, for the loan of blocks of a Knapsack Sprayer Eclair, Knapsack Dry Sprayer, Vermorel Nozzle, and Pal Injecteur; to the Ward-Love Pump Co., Rockford, Ill., U.S.A., for permission to reproduce Fig. 30; to Messrs. Weeks and Sons, Maidstone, England, for the loan of blocks of a Knapsack Sprayer (External Pump Pattern), Small Power Sprayer, Hop Sulphurating Machine, and Multi-Spray Adjustable Nozzle.

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R. A. W.
P. B.

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# CONTENTS

## CHAPTER IV



## CHAPTER V



# PART II. CHEMICAL CONTROL

## CHAPTER VI



## CHAPTER VII



## CHAPTER VIII

## CHAPTER IX



## CHAPTER X



## CHAPTER XI



## PART III. MECHANICAL CONTROL

## CHAPTER XII



## CHAPTER XIII

## CHAPTER XIV



## CHAPTER XV



## PART IV. LEGISLATIVE CONTROL

## CHAPTER XVI



## APPENDIX

# ILLUSTRATIONS

# PART I

## NATURAL CONTROL

## CHAPTER I

### HOST RESISTANCE

It has long been a matter of observation that, amongst the wild and cultivated plants or animals that act as hosts to insects, many examples occur of families, or even individual species and varieties, that are less liable to attack, or are less easily injured. They are, so to speak, *resistant.*

Such resistance may be so high as to confer actual *immunity* or may be so low as to constitute *susceptibility*. It may be of a general nature, a resistance to insects in general, as in the case of ivy or yew, or it may be partial; that is to say, the plant, though attacked by a considerable number of insect species, has established a state of equilibrium, the degree of the insect attack being rarely sufficiently intense to cause serious injury; or again, the plant or animal may be resistant only to one particular species of insect. Such partial resistance is shown by most wild plants, and such specific resistance may be exemplified by the Northern Spy and Winter Majetin varieties of apple, which are almost immune to the well-known apple pest Woolly Aphis (*Eriosoma lanigera*, Hausm.). Wild plants and animals are invariably less susceptible to the attacks of local insects than are domesticated or introduced varieties.

Undoubtedly such resistance is often more apparent than real and due to the existence of checks imposed upon the insect by parasites, by birds, or by disease, but the occurrence of such inhibiting factors must not be allowed to overrule the existence and importance of natural resistance factors inherent in the host. The American species of grape vine, *Vitis riparia*, is no less resistant to the attack of *Phylloxera* in the different environment of South Europe than it is in its native environment. The Chinese pear is just as much resistant to San José Scale in California as in its native country.

In all plants and animals, variations are liable to arise that can assist the plant to offer a certain degree of resistance to insect attack. Such variations may be very small, but quite a slight increase in such a factor as thickness of skin, or acidity of sap, can be shown to be sufficient to enable the plant or animal to survive attacks that would kill or cripple those that lacked the variation.

From what we know of the feeding habits of primitive orders of Insects, for example the Orthoptera and Isoptera, it would seem that the ancestral type of insect was an indiscriminate feeder, attacking impartially any type of plant; that is to say, it was *polyphagous*.

The liability of the plant, however, to be attacked by any species of insect would become discounted by the evolution of resistance factors, such as would tend to discourage a certain number of insect species. It is, of course, very unlikely that a plant would develop resistance factors sufficiently powerful to keep *all* insects at bay. Even the most poisonous and noxious plants serve generally as hosts to at least one or two species of insect, but the plant would have achieved a sufficient measure of success if the number of its insect guests became limited.

The effect upon the insect would obviously be a restriction in range of food-plants brought about—

(1) either by the insect confining itself to plants whose resistance factors were not sufficiently repellent,

(2) or by the insect becoming so adapted to the resistance factors of one plant or type of plant as to become incapable of normal development upon plants where such factors were lacking.

It is, of course, well known that many insects with a wide range of food-plants show marked avoidance of certain plants; the field-entomologist would say that they showed a *preference* for certain plants, a statement that very often conceals the real physiological significance of the habit.

Termites, for example, are notoriously indiscriminate feeders, yet, according to Fuller (1912), termites in Natal, whilst attacking most kinds of fruit trees, displayed a rooted objection to peach trees, so that advantage can be taken of this to graft most varieties of plum upon peach stocks; nor will they attack citrus trees, anonas, bananas, avocados, mangos, and loquats.

The San José Scale (*Aspidiotus perniciosus*), a widespread feeder, attacks all fruit trees except chestnut, fig, cherry, and vine; it readily attacks poplar, hawthorn, beech, *Ribes*, *Salix*, lime, elm, acacia, etc., but avoids cedar, hazel, magnolia, plane oak, and holly.

The Gipsy Moth (*Porthetria dispar.*, Linn.), again, is generally considered to be an indiscriminate feeder upon tree foliage, but investigations by Mosher (1915) and others would seem to indicate that even this notorious pest is restricted in habits, and that its food-plants may be divided into :

(*a*) A group of plants particularly favoured, including apple, mountain ash, larch, birch, lime, oak (most varieties), hawthorn, elder, poplar, willow, and hazel ;
(*b*) A group suitable only to older caterpillars, including chestnut, most pines and spruces ;
(*c*) A group on which only a few caterpillars can develop, including varieties of elm, hickory, hornbeam, maple, pear, and cherry ;
(*d*) A group *avoided* by the moth, including arbor vitae, arrow-wood, maple-leaved arrow-wood, black ash, blue ash, red ash, white ash, azalea, cedar, red currant, dogwood, cypress, grape vine, poison ivy, holly, sycamore, tulip tree, viburnum, walnut, honeysuckle, blackberry, raspberry, sarsaparilla, sweetbriar, mulberry, juniper, and some varieties of pine.

A wood consisting of a mixture of trees is attacked somewhat in proportion to the presence of favourite food material ; thus in a wood where few trees of class (*d*) are present, defoliation will be extensive. A natural remedial measure would be to ensure the absence from a forest or plantation in an area infested by this moth, of trees favoured by it. Thus in a pine wood containing a few scattered oaks, such oaks should be cut down so that the less attractive pines may be entirely saved from attack (Burgess and Rogers, Fiske).

The second way in which a primitively polyphagous insect might become dietetically restricted, namely, by becoming adapted to certain resistance factors and becoming unable to thrive in their absence, is exemplified by the numerous cases of species, or genera, or even whole families of insects, which feed only upon the members of certain plant families, or upon plants which possess similar factors.

Thus the larvae of the common butterflies *Pieris brassicae* and *Pieris rapae* feed only upon plants containing a particular glucoside, one of the mustard oils. Tragardh (1913), by smearing a paste containing this substance upon leaves which the caterpillar normally avoids, rendered such leaves attractive. Similar results were obtained with larvae of the herbivorous Hymenopteron *Priophorus padi*, which is attracted to members of the Rosaceae by the glucoside amygdalin.

It is doubtful whether there is any plant to whose resistance

factors no insect can adapt itself. Such total immunity has at various times been claimed for *Rhus*, *Aconitum*, *Taxus*, *Hedera*, *Abies cedrus*, but is probably local for the district where the observation was made. At any rate, the increased cultivation of medicinal plants (*Aconitum*, *Conium*, *Atropa*, *Hyoscyamus*, *Digitalis*, *Papaver*, etc.) during and since the war, particularly in Germany and Russia, has shown that such plants, though certainly highly resistant to insects in general, are liable to severe attack from many specific pests, and extensive lists of insects which habitually attack such poisonous plants have been published (Zacher, Parfentjev). Among the insects so listed, however, it must be noted that sucking insects are greatly in the majority.

The extreme type of specific food habit is seen where a particular species of insect feeds only upon a particular genus, or even species of plant. Thus the Coccid, *Coccus fagi*, is never found upon any other plant but beech, and is even extremely rare upon the copper variety of this plant.

The gulf between the indiscriminate type of feeder such as the locust and such a specialised feeder as the Beech Coccus is bridged by several stages that afford evidence as to the way one type may have evolved from the other. Thus, for example, there is the case of the specialised feeder retaining to some extent the primitive polyphagous habit, a case illustrated by the Aphid family. Most Aphid species show migration from summer to winter host plants. The winter host plant is generally single, or consists of a few closely related species, usually woody-stemmed plants. The summer host plants may be numerous and are not necessarily related botanically, but agree in being herbaceous.

It would seem that the winter host plant is the one to which the Aphid is becoming adapted, and that the attack upon the summer host plants is a relic of an ancestral polyphagous habit.

Now, suppose that when the Aphid species migrates from the summer plant to the winter one, some individuals remain behind, and likewise when the return migration occurs in the spring, individuals remain upon the winter plant. Such a habit has become established, for example, in the Aphid genus *Chermes*, where we find :

(*a*) Colonies which spend their whole existence on larch ;
(*b*) Colonies which spend their whole existence on spruce ;
(*c*) Forms which migrate from larch colony to spruce colony ;
(*d*) Forms which migrate from spruce colony to larch colony.

That is to say, the cross-migration habit has become partially suppressed in *Chermes*.

Certain other cases of Aphid life-histories would seem to show that such restriction of the migratory habit may to some extent be the result of climatic conditions. Davidson (1918) has pointed out that the semi-tropical climate of the southern and south-western states of America permits Aphides to feed and reproduce throughout the winter months, and thus several species which in the north alternate between summer and winter hosts, in the south pass the whole year on their summer hosts. *Aphis prunifoliae*, for example, in the north winters on apple and summers on grasses and cereals; in the south it never attacks apples.

Baumberger (1917) asserts that not only do tropical insects never hibernate, but that such insects introduced into temperate regions, where climatic conditions conduce towards hibernation, cannot be induced to hibernate. It is probable that amongst tropical insects there is a much greater preponderance of polyphagous feeders over specific feeders than in temperate regions, and that the proportion of the latter increases the farther one gets from the tropical zone.

A complete or nearly complete suppression of the cross-migration habit, arising after definite alternation of hosts had become established, would bring about the occurrence of distinct *biological races* of one species; one race confined to one type of food-plant, the other to another type of food-plant. Instances of such biological races are numerous.

Generally, each race becomes so adapted to its particular food-plant as to become quite incapable of using any other type of plant, and so quite unable to alternate with the other race.

Haviland (1919), experimenting with two morphologically identical species of Aphis, viz. *Aphis viburni* on the gelder rose, and *Aphis grossulariae* on *Ribes*, finds that the first migrant from *Viburnum* can form colonies either on *Viburnum* again, or on *Ribes*. The descendants of the migrants to *Viburnum* can be established on currant only with difficulty, and the resulting colonies rarely go beyond the third generation. The descendants of the migrants to currants cannot be re-established on *Viburnum*. That is to say, within two or three generations some change takes place in the currant form which prevents it from flourishing on gelder rose, or possibly the *Viburnum* itself undergoes some constitutional change during the summer, increases its tannin content, for example, so that the race on this plant can gradually adapt itself to altered conditions which the newly transferred currant stock cannot tolerate.

Biological races may be morphologically identical, but usually slight differences in appearance between the two races

arise. Thus in Canada the biological race of the Apple Maggot (*Rhagoletis pomonella*) that infests huckleberries is below the normal size; the normal apple-bred race will not lay eggs upon the huckleberry, nor will the huckleberry race oviposit upon apple.

Such morphological differences, though slight generally, may often be large enough to raise serious doubts as to whether they are to be regarded as *inter*-specific or *intra*-specific; as to whether, in fact, the two forms are not distinct species rather than biological races. In such a case, if the biological independence is rigidly maintained, the species on host *A* not thriving on host *B* and *vice versa*, and if the two forms are not fertile *inter se*, they can be looked upon as being distinct species. Unfortunately, however, such physiological demarcation is not always demonstrable; the feeder on *A* may not be unwilling to utilise *B*, particularly if *A* be scarce or absent.

The genus of biting-louse, *Pediculus*, offers an example of the difficulty of deciding between biological races and true species. Undoubtedly two distinct forms of *Pediculus* attack man, the head-louse—*P. capitis*—and the body-louse—*P. humanus*. They are quite distinct in habit, and, to some extent, distinct morphologically. *P. capitis* is somewhat less in size than *P. humanus*. There are differences also in shape of abdomen, in colour, and in formation of femora, tibiae, and tarsi of the first pair of legs of the male. By most authorities the two forms are looked upon as extraordinarily closely related species. There is, however, some evidence to indicate the possibility of their being biological races of one species.

Bacot (1917) has effected cross-pairing, and finds the offspring fertile *inter se*. Hybrid strains were produced until the F3 generation, and presumably could have been carried on indefinitely. Secondly, Sikora (1917) has reared normal head-lice on the human arm, and after the fourth and fifth generations these showed the morphological peculiarities and average dimensions of the body-louse.

Possibly many parallel instances occur, particularly in the more recently evolved Insect families such as the Tachinidae and among the Acalyptrate Muscidae, and many forms now claimed as distinct species may, in the light of fuller knowledge, prove to be biological races.

It must not be inferred that such biological races arise always from forms like *Chermes*, that show cross-migration between two different hosts. Biological races could quite well arise from a form that, having become restricted to a few plant orders, becomes biologically divided into groups, each adapted to a single order. Thus, in Australia, the fruit-fly genus *Dacus*

has two groups of species: (*a*) the *Dacus cucurbitae* group, breeding only on Cucurbitaceae, and (*b*) the *Dacus ferrugineus* group that never feeds on Cucurbitaceae. Within each group, again, biological differentiation of forms adapted to particular plant species could arise.

The border line between the biological race and the true specific feeder is thus often very vaguely demarcated, and probably all such specific feeders, though now distinct morphologically and bionomically, have passed through a biological race stage.

### Nature of Resistance Factors

Our knowledge of the exact nature of the factors that induce host resistance is at present fragmentary, but the scattered and isolated facts that have been noted indicate that such factors fall roughly into two categories:

1. *Physico-chemical*: thickness of integument, of seed coat, presence of hairs, of alkaloids, essential oils, acids, gums, etc.
2. *Physiological*: vigour, precocity, quick recovery from wounds, seasonal adaptation, absence of response to specific stimuli, etc.

Numerous examples could be cited regarding the influence of the *integument*. There is, for example, the immunity of the zebu race of cattle to the attack of the Texas cattle-fever tick (*Margaropus annulatus*). According to Mohler (1914) this immunity depends upon the secretion from the skin glands, the toughness of the skin, which though as thin as that of other cattle is more difficult to pierce, and upon the short coat. Similar factors render the bison resistant to the fever tick. The comparative freedom from tick infestation, characteristic of the semi-wild cattle of Texas, may thus be due to an infusion of zebu blood from early Spanish importations into Mexico, and from zebu cattle brought to South Carolina in 1849.

The nature of the cuticle is often of great value to plants. According to Picard (1913), the moth *Phthorimaea operculella* oviposits upon a great number of Solanaceous plants, but only upon rough surfaces, in cracks and depressions. Smooth-leaved flax, allied to Solanaceae, is immune, whereas the unrelated but rough-leaved *Cynoglossum* is visited by the moth.

*Tephrosia candida*, grown as a green manure plant in the more elevated plantations of Java, may lose up to 75 per cent of its seeds through the activities of an Anthribid beetle that oviposits on the seed pods. *Tephrosia vogelli* will remain immune from attack, even if amongst seriously

infested *T. candida*, owing apparently to rapid and early hardening of the seeds.

Again, Riaboi (1915) suggests that in the case of the Codling Moth (*Cydia pomonella*) the jaws of the caterpillar cannot break directly through the hard walls of the carpels, so that apples which have small, firmly closed carpels and no intercarpellary space will be immune to attack, but apples whose carpels are easy of access, their walls being disconnected in the upper part where the pollen tubes lie, will be attacked.

The presence of *alkaloids*, *essential oils*, *acids*, or *gummy substances* in a plant is often of the greatest importance.

Although no product of plant chemistry seems capable of providing total immunity, the variety of insects that will attack a plant with well-marked toxic or repellent juice is small.

The value of essential oils in the rind of the citrus fruit has been investigated by Back and Pemberton (1915) with regard to the Mediterranean Fruit-fly (*Ceratitis capitata*). Citrus fruits have long been regarded as peculiarly susceptible to the attacks of this fly, but according to these authors, although grape fruit, oranges, lemons, and many limes may become quite badly infested with well-grown larvae, if allowed to remain on the tree long after they become sufficiently ripe for the market, yet larvae are seldom found in the pulp before ripening. This cannot be explained on the view that the pulp of the unripe fruit is too acid to permit larvae to exist, for investigation has shown that no citrus fruit, not even lemon, is too acid to inhibit the development of such larvae. The explanation seems to lie rather in the toxic effect of the essential oil, contained in the oil-cells of the rind, upon the eggs of the fly. In puncturing the rind to form an egg-cavity, the female can scarcely avoid bursting at least one or two oil-cells. The oil thus liberated, though insufficient to repel the fly, is sufficient to destroy the eggs or newly-hatched larvae. In fact, only the persistent attacks of successions of larvae from different batches of eggs laid in the same puncture, in which the oil has become inoperative, seems able to break down the barrier between young larvae and pulp.

A further instance of the value of essential oils is given by Hagen (1855), who asserts that the high resistance of teak (*Tectona grandis*) and ironwood (*Sideroxylon*) to termite attack in India is not a question of hardness, since Asiatic termites will attack the hardest wood (*Lignum vitae*), but is due rather to the wood containing oils or alkaloids repellent to the insects. Similar evidence has been brought forward recently by a Japanese observer Oshima, who, as a result of testing the relative resistance of forty-five species of native and

exotic trees in Formosa to termites, states that teak and cypress pine (*Callitris glauca*) are absolutely immune to the attack of these insects, their resistance being due to the presence of a sesquiterpene alcohol.

According to Sharples (1918), the general opinion held by planters in the Middle East is that small boring beetles such as the Scolytid *Xyleborus parvulus*, and the Longicorn *Pterolophia melanura*, cannot penetrate the bark of a healthy rubber tree without being killed by the latex, and only when the laticiferous cells have been killed by fungi can such beetles reach the wood. Experiments seem to show, however, that the resistance is due chiefly to the corky layer. Removal of this greatly increases the susceptibility of the tree to attack. If the cortical layer be injured or removed by fire after a spell of dry weather, the scorched tree is quickly attacked by borers, many of which reach the wood in spite of the exuding latex.

Among acid juices, malic acid seems to be the most effective. *Rhagoletis pomonella*, the Apple Maggot, in Canada infests sweet and sub-acid varieties (summer varieties) in preference to the acid autumn and winter kinds.

*Rhagoletis cerasi*, the Cherry Fruit-fly of Europe, is said not to occur in varieties of cherries with acid pulp, such as Hortense, Reine, Montmorency, and Royale, nor in the wild cherry, but occurs especially in Whitehearts and Bigaroons.

The obvious benefit to a plant of poisonous or repellent sap suggests the possibility of obtaining the effect of a poisonous juice by artificial injection with a chemical, and many experiments in such artificial immunisation have been carried out.

Dementiev (1914) has succeeded in introducing large volumes of liquid into plants by means of a rubber tube placed over the cut surface of a root or branch and connected with a vessel, filled with the solution, suspended on the tree. The transpiration of the plant brings about suction of the fluid through the cut surface. In twenty-nine and a half hours, ten and three-quarters litres of an aqueous solution of arsenious acid (0·2 per cent) were introduced into an apple tree.

The speed of absorption depends upon the diameter of the cut surface and on the rate of transpiration. Colloids are scarcely absorbed at all, and crystalloids vary greatly in their rate of absorption. Chlorides are absorbed fairly rapidly, sulphates less so, carbonates least of all. Introduction under pressure was tried and was apparently without ill effect on the plant if the pressure did not exceed eight atmospheres. Remarkable success in the treatment of apple trees infested with Woolly Aphis is claimed; injection of barium chloride (1 : 350) through the roots brought about the disappearance of the

Aphides within ten days. The dose varies from 0·3 to 1·6 grams of barium chloride.

Sanford (1914) claims good results in the extermination of Fluted Scale (*Icerya purchasi*) upon Spanish Broom (*Spartium junceum*) by boring a hole three inches deep by three-eighths in diameter in the bark, and plugging with crystals of potassium cyanide; within three days the Scale insects began to drop off, apparently dead.

Shattuck (1915) reports similar success with elms and black-locust trees, large groves in Kansas having been completely saved from boring and girdling insects by these means.

On the other hand, Moore and Ruggles (1915) assert that hydrocyanic acid gas travels up a tree *via* the old tracheae, and as boring insects live generally in the cambium, artificial injection of trees with potassium cyanide is useless against such insects. Even to be effective against sucking insects, the gas would have to traverse the vascular system or between the vascular system and outer surface, a procedure that would probably kill herbaceous and semi-woody plants. Woody trees are not endangered by the gas, except in excessive amounts, since the gas is in the dead tracheae.

Andrews (1919) has applied injection methods to the control of the Mosquito Blight (*Helopeltis theivora*, Waterh.) of tea in Northern India. It has been established that a high ratio of available potash to available phosphoric acid in the soil in which the plants are grown acts inimically upon the insect pest, the tea bushes showing a greater resistance to the pest. Apparently, however, the plant is not always able to make use of the potash in the soil, nor able to benefit from potash manures applied to it. The direct injection of the bushes, therefore, with potash has been tried and has been convincingly successful, plants heavily infested with *Helopeltis* quickly becoming free and ceasing to attract other Helopeltis individuals.

It is clear, however, that in this case the aim in view differs in principle from the experiments mentioned above, since there is no question here of creating an artificial toxicity of the tree sap, but merely the encouragement or development of some resistance factor inherent in the plant.

In this connection, a recent article by Howard (1921), discussing the influence of soil factors upon disease resistance in plants, suggests that the condition of the active roots may influence the cell sap throughout the shoot system, and so profoundly affect the resistance of the plant to the attacks of parasites. Thus soil conditions may play a most important part in determining the degree of resistance that a plant can offer to the attack of an insect pest.

### Physiological Factors

Resistance to insect attack afforded by vigour, growth, precocious or delayed maturity, proliferation, etc., is not, strictly speaking, true disease-resistance, yet numerous examples could be brought forward to show that such factors may play a very important part in the ability or inability of a host to withstand insect depredations.

Highly cultivated, or sickly, or very young plants are extremely susceptible to the attacks of insects.

In the southern area of U.S.A., a Dynastid beetle (*Lizyrus rugiceps*) injures maize by entering the young stalks just below the surface of the ground and travelling upwards to destroy the growing point. A plant three feet high is not liable to be damaged, the growing point being almost out of reach, and full-grown plants are practically immune.

Again, in the northern area of U.S.A., cultivated varieties of apple are rarely injured by the Apple-seed Chalcid (*Syntomaspis druparum*), a pest of crab-apples, owing to the fact that at the time the Chalcid appears, the cultivated fruit is usually too large to permit of the insect's ovipositor reaching the seeds.

How far host resistance may be looked upon as an absence of response to a definite stimulus, is disputed. Many instances of hypertrophy of vegetable tissues are known to result from wounds inflicted by insects, and it is generally believed that such abnormal development is due to some substance injected into the plant by the insect, to whom the hypertrophy is advantageous. Thus in the case of Big Bud disease of black currants, it would seem necessary to the mite that produces the disease that the growing point of the black-currant shoot should respond to the wound stimulus and produce the hypertrophied bud, for the immunity of the red currant seems to be due merely to an absence of such response, and Lees (1918) has shown that the immunity of an apparently mite-resistance strain of black currants is due to the growing points persisting under the attacks of the mites, and so affording no food-supply to the attacking organisms.

Such failure of wounded tissue to respond to the injection of the insect may be due :

(*a*) to an absence of a particular substance which reacts to the stimulus and stimulates growth ;
(*b*) to the presence of a specific anti-body which counteracts the effect of the insect poison.

From analogy with other facts of immunity, the latter view would seem the more likely.

On the other hand, cases are known where hypertrophy of wounded tissue is actually inimical to the insect, and so brings about the phenomenon of host resistance in a different manner.

In many varieties of American Upland cotton, for example, the cotton boll responds to the attack of the weevil *Anthonomus grandis* by cell proliferation, a soft pulpy tissue of large thin-walled cells resulting, and the effect of simple mechanical pressure of such tissue upon the contained weevil larva may produce a mortality estimated at 6·14 per cent. As such proliferation can be produced artificially by needle punctures, it is probably not a response to an injurious insect-secretion, but is an abnormal manifestation of a tendency, inherent in plant cells, to repair an injury through irritation, by forming new cells.

### Utilisation of Host Resistance Factors

The effect of cultivation upon plants may be said, generally speaking, to bring about a reduction of vigour and an elimination of acid or astringent juices ; the susceptibility of the plant is therefore usually increased by cultivation and any inherent resistance weakened, and, although plant-breeding experiments, aiming at the production of strains which will combine the qualities desired by the cultivator with the qualities essential to plant resistance, have achieved many successes in the case of resistance to fungoid and bacterial diseases, successful results in regard to insect-resistant varieties of plants are not so numerous.

There would seem to be three courses open to the breeder who desires to utilise such resistance factors as are exemplified above, namely:

1. **Selection,** either pure line or mass selection of varieties which combine resistance factors with other desirable qualities.

2. **Hybridisation,** between resistant individuals and individuals not resistant but possessing horticultural advantages.

3. **Graft Hybridisation,** the grafting of desirable strains upon resistant strains.

**Pure line selection,** the isolation of and further propagation of resistant varieties or species, has not proved very applicable, mainly because such natural resistant strains are generally inferior as regards their commercial utility to susceptible strains.

**Mass selection,** that is to say, the selection of a number of

plants from a main crop and the sowing of their seeds *en masse*, has been resorted to in order to obtain an early maturing strain that would avoid the main ravages of boll-weevils.

The production of resistant strains of plants and animals by **hybridisation** between resistant and susceptible species or varieties has been accomplished in numerous instances and promises much for the future. Hybrids between *species* are usually intermediate in character between the two parents, being thus less resistant than one parent but more so than the other parent; the loss of resistance is, however, often compensated for by the vigour of the hybrid. It is true that such vigour may be associated with sterility or partial sterility, but this feature, though leading to lessened production of seed, may not be accompanied by any deficiency to yield when the plant can be propagated vegetatively.

A good example of the value of inter-specific hybridisation is afforded by the observation of Gernert (1917) that hybrids between Teosinte (*Eucloenia mexicana*) and Yellow Dent Corn (*Zea mays indentata*) are completely resistant to the attacks of the maize root aphis *Aphis maidi-radicis* and the maize plant aphis *Aphis maidis*, both of which are highly injurious to maize. The hybrids thus resemble the parent Teosinte, and probably, as the parent does, owe their resistance to the more serrated leaves and sweeter sap than the maize possesses.

Another example is afforded by the Kieffer and Leconte varieties of *Pyrus*, which are F1 hybrids between the Chinese Pear (*Pyrus sinensis*) resistant to San José Scale, and the susceptible *Pyrus communis*. These varieties approximate in quality to the best varieties of *Pyrus communis*, but in resistance powers resemble the *Pyrus sinensis*.

The resistance offered by the zebu and the bison to ticks has already been mentioned. In the cattle-rearing areas of Southern U.S.A., where the comparatively high resistance offered by the range cattle to ticks has been lowered by attempts to improve the breed by the use of pure-bred Hereford and Shorthorn bulls, the heavy losses in the cattle industry, due to the tick-conveyed Texas cattle fever, have stimulated inquiry into the possibility of hybridising pure-bred cattle with the tick-resistant zebu or bison, in the hope of obtaining cattle proof against the disease, yet of superior market qualities. Bison hybrids are superior to zebu hybrids in respect to flesh and coat, and superior to either parent in size and vigour, but males are always sterile, and there is a great mortality of female parents at calving, owing apparently to the physical difficulties involved by the hybrid possessing a considerable hump like the bison. On the other hand, in the case of zebu

hybrids, both sexes are fertile; the hybrids, like the parent, are resistant to foot-and-mouth disease, to anthrax, and to splenetic fever, and though not immune to the Texas fever organism, are immune to its carrier, the tick. They possess more vigour than either parent, and if the cross be between zebu and Hereford they more nearly resemble the northern breed, except for the slight hump and dewlap (Babcock and Claussen).

Hybridisation between varieties depends for success upon immunity behaving as a Mendelian dominant. As an example may be taken the breeding of sweet corn in Southern U.S.A. resistant to the caterpillar *Heliothis obsoleta*. Sweet maize is difficult to grow in the tropics, owing to the ravages of this cutworm, the entire crop sometimes succumbing, but native field varieties seem to suffer little injury, owing apparently to the extent to which the husks overlap the ear. The early seasonal varieties preferred by cultivators generally have poorly developed husks. Crosses between commercial varieties and native varieties produce hybrids with distinctly greater resistance than the commercial sweet varieties, and with greater vigour, but showing no inferiority as regards commercial qualities.

In Barbadoes, Harland (1916) claims to have produced strains of Sea-Island cotton and Upland cotton that are resistant to Leaf Blister Mite (*Eriophyes gossypii*), by hybridisation on Mendelian lines between susceptible Sea-Island and Upland varieties and resistant native strains.

**Graft hybridisation** is undoubtedly the oldest method of utilising inherent resistant factors. It has long been the custom of fruit-growers, particularly in Australia, to graft strains of apples susceptible to American Blight (*Eriosoma lanigera*) upon root stocks of the Northern Spy and Majetin varieties of apples, these being highly resistant to this insect.

The most illuminating example of the value of graft hybridisation, however, is afforded by the case of the vine aphis *Phylloxera*. *Phylloxera vastatrix*, Planchon., the vine aphid, has a life-cycle confined to the grape-vine but including root-feeders and leaf-feeders. The leaf-feeders (gall makers) are comparatively harmless, the root-feeders distinctly injurious to vines. On the vine roots, the root-feeding aphids produce (*a*) small galls (nodosities) near the tips of the young rootlets, (*b*) large swellings (tuberosities) upon older rootlets and roots. The first class of root gall occurs on all vines, resistant or susceptible, if *Phylloxera* be present, and thus are not particularly injurious. The difference between susceptibility and

resistance to *Phylloxera* is, in fact, a question of the numbers, size, and penetration of the tuberosities.

The original home of this species of *Phylloxera* is generally regarded as being America, although a certain amount of evidence has been brought forward to indicate the possibility of the region around the Black Sea being the place of origin. Certainly America is the home of the majority of the *Phylloxera* species, and nearly all species producing leaf galls occur there exclusively. Börner (1921) has made the interesting suggestion that the original habitat of *P. vastatrix* was the uniformly moist rain forests of the tropics and sub-tropics, where, infesting the genus of vine *Vitis*, the insect was able to live not only in leaf galls, but on all parts of the plant both above and below ground. The present-day type of root-form may have become fixed in adaptation to life in drier regions.

The vine-louse was discovered on an American vine by Fitch in 1854, and later on it was found on wild vines in the Mississippi basin. It was not known in Europe before the 'sixties, and was almost certainly introduced upon vines imported from America.

The wild vines of America show all gradations of resistance to the *Phylloxera*, from almost complete immunity to complete susceptibility. Probably the insect has gradually adapted itself to certain varieties. The more resistant species belong to the subgenus *Euvitis*, and are, in order of resistance, expressing the maximum or absolute immunity as 20, as follows: *E. rupestris*, 18-19; *E. riparia* and *E. cordifolia*, 18; *E. berlandieri*, 17; *E. cinerea*, 16; *E. aestivalis*, *E. linsecomii*, and *E. candicans*, 14-15.

On the other hand, the species of vine to which the three thousand or so European varieties belong, viz. *Vitis vinifera* and *Vitis silvestris*, have proved highly susceptible to the introduced *Phylloxera*, so much so that viticulture in Southern France and Italy was severely checked by its appearance.

The hope that it would be possible to obtain hybrids between resistant American vines and *Vitis vinifera* equal in size, quality, and yield to the latter parent, has proved futile, since resistance to *Phylloxera* and quality of fruit seem to a great extent to be antagonistic qualities; the hybrids yielding the best wine are usually insufficiently resistant, and *vice versa*. A vast amount of work has been done and many thousands of these hybrids, generally termed "direct producers," raised, most of which are valueless, except in some cases as resistant stocks against cryptogamic diseases. The only practicable method, in fact, of dealing with *Phylloxcra* in an infested district lies in the use of graft hybrids, the grafting of *vinifera*

varieties upon *Euvitis* root-stocks. Matters would be fairly simple for the vine-grower if one universal resistant stock could be found, suitable for all climates and soils; but no such ideal stock is available and a large number of stocks are in general use. In the main, root-stocks of the species *rupestris* and *riparia* are used, or of hybrids between *riparia* and *berlandieri*, or of crosses between such hybrids and certain varieties of *vinifera*.

# CHAPTER II

## CLIMATIC RESTRAINTS

THE fact that climatic conditions exercise some kind of control over the prevalence of insects has always been realised. The coincidence of an outbreak of an insect pest with a period of warm wet weather during the growing season has been remarked upon for many years, but the manner of the occurrence of insect infestations and their relation to climatic conditions have never been clearly understood and have not until recently been investigated.

Much confusion has arisen because, although many records of climatic phenomena associated with seasonal variations in the appearance of insects have been made, they have not been based upon sufficiently accurate and authenticated observation. One great difficulty in the interpretation of such facts as have been recorded arises from the physical inability of the few isolated investigators, who have studied this subject, to cover more than a small portion of the whole field of climatic phenomena, and the consequent limitation of the piece of investigation to the response one particular form of insect may show towards one climatic factor, such as humidity or high temperature.

There is, in consequence, great divergence of opinion as to the degree of influence exerted upon insect life by climatic factors.

Different writers have ascribed to a different single factor the credit of predominant influence upon insect life. The establishment of a single climatic factor as a standard that will express the exact measure of meteorological influence over the animal has been attempted by many writers. Amongst other standards the following have been suggested: *Mean Daily Temperature above 6 degrees C.* (De Candolle), *Total Temperatures* (Merriam), *Minimum Temperature* in some cases (Sanderson), *Atmospheric Moisture* (Walker), *Relative Humidity*, and *Saturation Deficit.*

The attraction to an investigator of this idea of a standard will be understood when it is realised that, if the occurrence of the insect pest could be attributed, say, to a certain total temperature during the growing season, the whole art of insect control could be reduced to a mathematical calculation, for it would not be difficult to ascertain under given conditions the time of the year that general infestation would commence, and preventive measures could be taken accordingly.

Improved experimental methods have indicated, however, that in the case of many insects the animal is influenced to a great extent by several factors acting together, and it is not possible, therefore, to accept any of the standards suggested, since they do not express completely the influence of a sum-total of factors.

In searching for a convenient standard to indicate this complex of factors, Shelford (1913) and others have advocated the adoption of what is termed the *Evaporative Power* of air. According to Hann (1903), "The total effect of air temperature, pressure, relative humidity, average wind velocity, upon a free water-surface in the shade or in the sun, is expressed in the amount of water evaporated." Further, according to Reinhard, the same factors have been shown to determine the amount of evaporation from the bodies of animals.

The mode of operation of this complex of factors upon the animal metabolism would seem, according to Shelford, to be somewhat as follows. The body temperature of an animal, whether a "warm-blooded" or a "cold-blooded" animal, is nearly always higher during activity than the temperature of the surrounding medium. A moist cold atmosphere (very low evaporation) will, owing to rapid conduction of heat, decrease the body temperature and *decrease* metabolism in a *cold-blooded animal*, and *increase* metabolism in the case of a *warm-blooded animal*, within the limits of its capacity for heat regulation. Such a heat-loss is less pronounced with a dry cold atmosphere, owing to less rapid conduction of heat. In a dry warm atmosphere (high evaporation), the rapid rate of evaporation keeps down the peripheral temperature of the animal, prevents excessive metabolism and too rapid rise of temperature, which would be fatal to a cold-blooded animal; in a warm-blooded animal, the high evaporation permits regulation of the body temperature and so saves the animal from heat-stroke and death. In a moist, warm atmosphere death and heat-stroke occur readily, owing to lack of evaporation and lack of peripheral cooling, in the case of warm-blooded animals, even if the surrounding temperature is only normal or even below normal.

Wind movement increases evaporation and encourages

radiation of body-heat. The animal's body is thus cooled, and, within limits, metabolism is *increased* in warm-blooded animals and *decreased* in cold-blooded ones.

Decrease of atmospheric pressure also increases evaporation and heat-radiation, and influences metabolism much as wind movement does.

The adoption of Evaporative Power, since it constitutes a sum-total of factors, would overcome to a great extent the difficulty of finding an adequate standard. The amount of evaporation can be measured by the Livingston atmometer, which consists of a cup of porous porcelain about five inches long by one in diameter. This is filled with water and closed with a rubber stopper through which a short piece of glass tubing passes. It is placed cork end downwards and the tubing is connected with a bottle of water. When evaporation takes place, the cup remains full but the level of the water in the bottle sinks, the number of cubic centimetres of water evaporated per hour thus being measurable. Differences in the rate of evaporation can be correlated with changes in temperatures, air moisture, air movement, and air pressure. Black, brown, or other coloured cups are used to determine the effect of light, and generally show in sunlight a greater amount of evaporation than white ones do.

The original type of cup was a cylinder, but an improved spherical type (Standardised White Spheres) is in many ways preferable. Black cylinders can be obtained for studies of sunshine as distinct from other evaporation features. The instruments are used both in the laboratory and in the field, where they are the only instruments that record the effect of wind movement and exposure to the sun, as well as temperatures, etc., in any terms of physiological significance.

Although the Evaporative Power may be considered the best available index of the complex of climatic factors, it is probable that it will not remain true for all conditions, nor is it improbable that many insects are affected more particularly by one climatic factor than by the complex. Consequently it is imperative to take into consideration, so far as is possible, not only the Evaporative Power as an index of the whole complex, but the independent influence of each factor also.

Of these factors, the ones of major importance are undoubtedly *air temperature, air humidity, precipitation* (rain and snow), and *air movements.*

The effects of these factors, either separately or in conjunction, may be :

1. An extension or diminution of the area of geographical or environmental distribution.

2. The production of definite physical characteristics, winglessness, coloration, etc.
3. An effect upon the habits of the insect under consideration ; upon migration, time of hibernation, aestivation, etc.
4. An alteration in the rate of the insect's metabolism, constituting :
   (*a*) An actual cessation in the rate and a consequent mortality of certain stages of the life-cycle ;
   (*b*) A general retardation of the rate, bringing about such phenomena as periodical hibernation, torpor, etc.
   (*c*) A retardation or prolongation of one or more life-cycle stages and a consequent lengthening or shortening of the whole life-cycle or the number of broods ;
   (*d*) A similar retardation or prolongation *not* resulting in any alteration in length of the whole life-cycle, the normal rhythm of existence being apparently so fixed by heredity that any shortening or lengthening of one stage must be counterbalanced by an inverse alteration in the length of succeeding stages.

These effects may now be discussed in detail.

In any study of insect *distribution*, either geographical, vertical, or environmental, it is important to distinguish, so far as is possible, the effects arising from *direct* climatic influence from those effects which are brought about by *indirect* climatic influence, as for example the action of climatic and soil factors upon vegetation. So far back as 1894, Merriam postulated that in U.S.A.—

1. Animals and plants are restricted in northward distribution by the total quantity of heat, that is to say, the sum-total of mean daily temperatures above 43 degrees Fahrenheit during the season of growth and reproduction ;
2. Animals and plants are restricted in southward distribution by the mean temperature of a brief period during the hottest part of the year.

That a total temperature, a minimum quantity of heat, is necessary to the normal development of an insect species, has been affirmed by numerous observers. Sedlaczek (1917), for example, asserts that in Europe, the Tussock Moth (*Lymantria monacha*) requires a sum-temperature of 2732 degrees Fahrenheit in order to complete its post-embryonic development ; until the aggregate of daily mean temperatures in a particular region attains to this figure, the moth will not appear in any large numbers, and the sooner this temperature aggregate is reached during the season, the longer will be the flight period

of the moth. Howard, also, has shown how the range of the Yellow Fever Mosquito (*Stegomyia calopus*) is determined by temperature, and how the exact limitations of the regions in which this mosquito, if accidentally introduced, might be expected to become established, can be determined by calculating the accumulated daily mean temperatures.

Sanderson (1908) has drawn attention to the danger of neglecting the fact that in summing up daily temperatures, only the excess of temperature above a " critical point " should be taken into consideration. The " critical point " may be defined as that point of temperature above which active metabolism occurs, and above which the accumulation of temperature affects the times of definite transformation in the organism, such as the leafing and flowering of plants, or the emergence from hibernation, the hatching or the metamorphosis of insects. This Critical Point, or Zero of Effective Temperature, has been regarded by many entomologists as being about the same for all insect species, and the point 43 degrees Fahrenheit has been fixed upon as representing it, but it is extremely probable that this Critical Point will vary not only with the other degrees of climatic influence, differing, for example, with each degree of humidity, but will not be the same for different insect species.

The conception is borrowed from the work of European botanists, and the application of it to entomology, that is to say, the supposition that in *an insect there is an accumulation of mean daily temperature, above the critical point for the species, which will bring about emergence from hibernation or will carry the insect forward to the next stage in its life-cycle,* is somewhat new. This temperature total is generally termed the **effective temperature.**

An ingenious method of deciding the time of arrival of migrating cotton boll weevils in any particular area, devised by Martin, will serve to illustrate the eagerness on the part of American entomologists to make practical application of this principle. The temperature total necessary to the development of the respective life-cycle stages of the weevil has been determined, so that the age of any weevil stage can be stated in terms of effective temperature ; if, then, the effective daily temperature, dating back from the day upon which a particular weevil stage may have been discovered, is summed up until the total reaches the amount necessary for the weevil to develop from oviposition to that stage, a date is obtained which will be the date of oviposition, and in all probability the date upon which the parent weevil reached the area.

It would seem evident that a Total Effective Temperature

for an insect or an insect stage obtained by addition of mean daily temperatures will have a different value for the winter months, when the mean daily temperature fluctuates considerably, than for the summer months, when the temperature is fairly constant from day to day. That is to say, a Total Effective Temperature obtained in this way will not be a constant throughout the year.

Experiments concerning the hatching of the eggs of the Cattle-tick *Margaropus annulatus* carried out by Hunter and Hooker (1908) indicate that the effective temperature in Texas, necessary for these eggs to hatch, is for the period April and May, 981·6 to 1139·1 degrees, whereas for the period September to October it is 837·6 to 1510·8 degrees Fahrenheit. The shortest incubation period occurred when the accumulated effective temperature was highest, and the longest incubation when the accumulated effective temperature was lowest; that is to say, the length of the incubation varies inversely with the total temperature, and in winter the incubation period is longer than in summer.

How, then, can the Effective Temperature be expressed in such a way as to remain true all through the year for the particular insect stage it is meant to indicate?

It has been suggested by Sanderson (1908) that in order to secure for the life-cycle of any particular insect species an Effective Temperature that shall have a constant value, a temperature curve should be obtained for the species based upon the observation of a considerable number of individuals kept at different constant temperatures, or, better still, at temperatures having a daily variation with constant maximum and minimum, and with fairly constant moisture conditions.

With such a curve plotted it should be possible to give each degree of temperature a definite value in relation to the accumulation of temperature necessary for any stage of growth or activity at the optimum temperature. Thus in the case of the cattle-tick, if the optimum be considered to be 28 degrees Centigrade, at which temperature 21·5 days are required for the eggs to hatch, then each day at 28 degrees Centigrade has a value of 4·65 per cent of the whole, or ·0465. As 25 days are required at 25 degrees Centigrade, each day at 25 degrees Centigrade has a value of ·04, and so on, the value of a day at 20 degrees Centigrade being ·02, at 15 degrees Centigrade being ·01, and at $11\frac{1}{2}$ degrees Centigrade being ·00666. A table for the value of the degrees between these points may now be made, so that the value of every degree to be considered may be given. Using these values, when an accumulation of 100 per cent or 1 has been reached, the true Effective Temperature,

or, to use Sanderson's term, the *Thermal Constant*, should have been obtained, since the time-relation to the varying temperatures has been reduced to a common unit. If in a similar fashion the effect of different degrees of moisture at each degree of temperature were determined, it would be possible to give a value for each degree of temperature which, when the total equalled 100 per cent or 1, would give the true physiological constant for the stage of growth or activity concerned.

The first of Merriam's laws, that northward distribution is dependent upon a sufficient summation of temperature over 6 degrees Centigrade, has been found to have many exceptions to it. Sanderson (1908) suggests that such northward distribution is determined to a large extent by the minimum temperature attained during the winter, and that where the average annual minimum temperature is below that at which a species can exist, it will never become abundant, though possibly some individuals would always survive in sheltered situations.

There is, in fact, a considerable mass of evidence as regards the effect of climate conditions upon insect metabolism tending to support Sanderson's contention.

According to Bachmetjew (1902) (Fig. 1), there is for every species of insect a definite range of temperature (K-W in figure) between whose extremes the insect is active; at one point in the range, the activity is greatest, and increase or decrease of temperature from this point retards metabolism; this point is the *optimum*. At temperatures beyond the upper extreme, metabolism is greatly retarded; up to a point A, death ensues in time; between A and a higher point B, death is instantaneous owing to heat-rigour. A limited length of exposure to a temperature between W and A will therefore not immediately kill the organism, but a constant temperature will do so.

Similarly, if the temperature be lowered below K, activity ceases; if it be lowered below freezing point to a point $T_1$, termed by Bachmetjew the *critical point*, the internal heat of the insect arises suddenly to a point $N_2$, and if the insect be restored to normal temperature it will usually revive after an interval dependent upon the length of time it has been undercooled. If, however, the body temperature again falls below the critical point, as at $T_3$, then death ensues.

Death at low temperatures is believed to be due to molecular rearrangement and tissue injury, whereas death at high temperatures seems due to protein coagulation. The relation of both excessive heat and excessive cold is dependent, therefore, upon the time involved and upon the rapidity with which the organism is cooled or heated and with which it is subsequently brought back to normal temperatures.

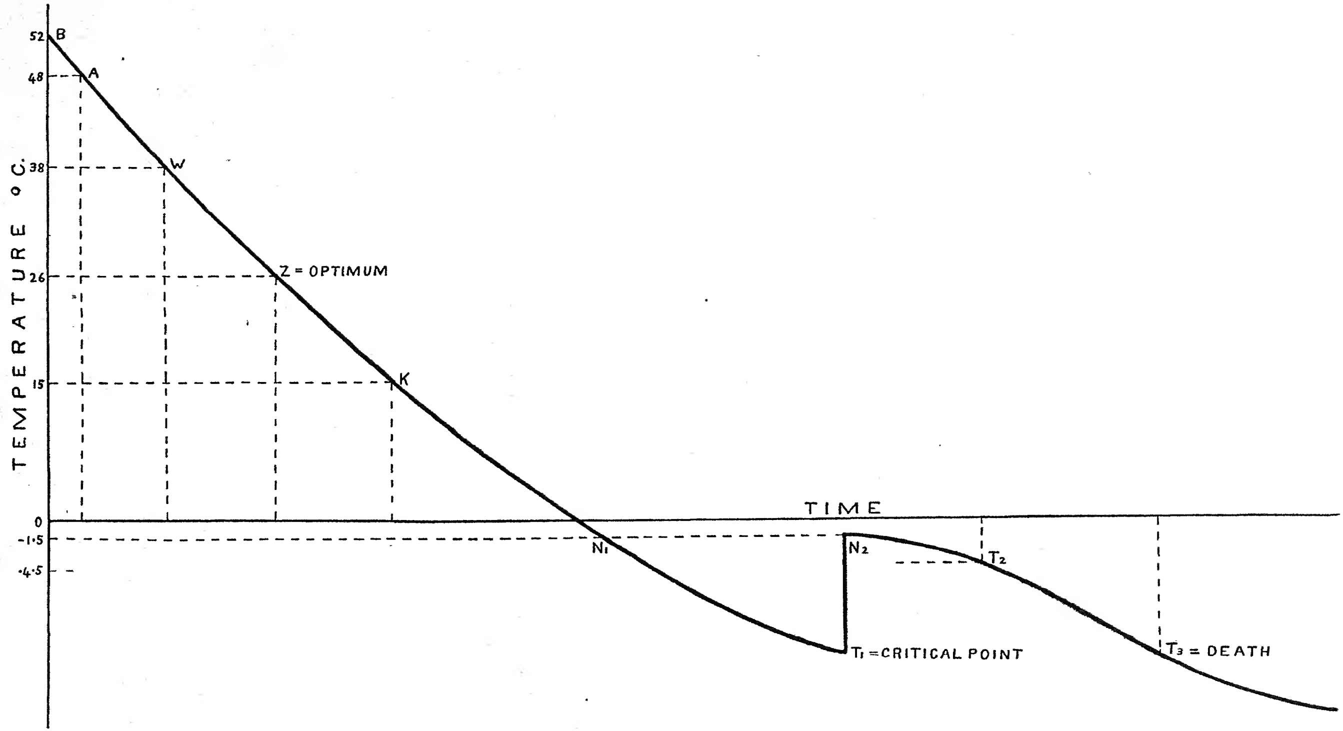



FIG. 1.—Relation of temperature to insect activity. (After Bachmetjew.)

Davenport (1897) has brought forward very similar views but uses a different terminology. The higher temperature at which metabolism ceases is termed the *maximum*, and that at which death is immediate, the *ultra-maximum*. The low temperatures are similarly termed the *minimum* and *ultra-minimum*.

In the case of the humidity factor also, Bachmetjew suggests that there is for each insect species a degree of atmospheric humidity which, being most favourable to the maximum rate of metabolism, may be termed the *optimum*; this optimum varies not only for each species but for each stage of each species, possibly for each stage of each individual. Whether there is in addition a maximum or ultra-maximum, and a minimum or ultra-minimum, has not yet been settled. That prolonged exposure to dry air is fatal to an insect seems certain, and exposure to saturated air is injurious to the insect, at any rate indirectly, by encouraging fungus diseases and digestive troubles.

An interesting method of expressing in graphical form the correlated effect of temperature and humidity together upon insect metabolism, has been suggested by Pierce (1916), the principle being to express the Zero of Effective Temperature not as a definite point but as a curve, each point on which represents the zero for a particular degree of humidity.

For any given insect there are definite boundaries of temperature and humidity which limit metabolism, activity, and development. There is, of course, a temperature *below* which even for a moment life is impossible, the *Absolute Minimum Fatal Temperature*; there is likewise an *Absolute Maximum Fatal Temperature*, above which life is impossible. Similarly, *Absolute Dryness* is more or less prohibitive of life, and so is *Absolute Humidity* or Saturation, although insects vary greatly in their ability to withstand extremes of humidity. Thus the graphical figure expressing the correlated influence of temperature and humidity upon insect metabolism will have four definite boundaries.

Within these limits, however, the varying conditions will permit the activities of an insect to attain toward, or decline from, a certain maximum efficiency, believed by most writers to be reached at a certain point termed the *optimum*. Pierce suggests that this optimum is better regarded not as a point but as a zone of humidities and temperatures, of more or less restricted area.

At any ordinary degree of humidity, starting from the *Absolute Minimum Fatal Temperature*, as the temperature increases, a longer and longer time of exposure is required to

kill the insect, until a point is reached at which life continues indefinitely. This range of temperatures, between the Absolute Minimum and this latter point, may be termed the *Zone of Low Fatal Temperatures* for that particular degree of humidity. Between the upper extreme of this range and the Zero of Effective Temperature, *i.e.* the point at which metabolism or growth begins at a given humidity, there is a range of temperatures constituting a *Zone of Inactivity*. At the lower end of this range of temperatures, complete dormancy without metabolism is found to occur, but as the temperature increases a gradual approach to sensibility is noted ; first metabolism, next movement, then the necessity for feeding.

Above the Zero of Effective Temperature, activity is at first sluggish, but increases with temperature, until the so-called " optimum " is reached, beyond which the rising temperature is accompanied by less and less activity and is finally accompanied by stupor and even sleep or coma. At the point of coma a second *Zone of Inactivity* commences. As the temperature increases, the sleep becomes more and more sound until a point occurs at which death comes after long exposure. At this point begins the *Zone of High Fatal Temperature*, within which death occurs at shorter and shorter periods, until it is instantaneous at the *Absolute Maximum Fatal Temperature*.

In a graph the limits of these temperature zones may be marked as along a vertical temperature scale.

Similarly, points along a horizontal humidity scale would indicate the limits of various zones of humidity, starting at Absolute Dryness and reading, from left to right, toward Absolute Humidity. Thus could be shown the Zone of Fatal Dryness causing Stupor, Increasingly Effective Humidity, Optimum Humidity, Decreasingly Effective Humidity, Excessive Humidity causing drowsiness, and finally Fatal Humidity.

The point at which the vertical and horizontal curves intersected would represent the centre of a zone of optimum conditions of temperature and humidity. If this point be plotted for each degree of temperature and humidity between the limits, the points will be found to lie along a definite curve ; in the case of Fig. 2, calculated for the Cotton Boll Weevil, the curve is an ellipse with the horizontal and vertical straight lines as axes ; the various zones of activity will be, in fact, represented by a series of parallel curves, in this case by a series of concentric ellipses.

Other observers, for example Headlee (1917), would attach great importance to the *water-optimum*, that is to say, to the amount of body fluid which permits the maximum of metabolic reactions, the necessary physical and chemical changes, to take

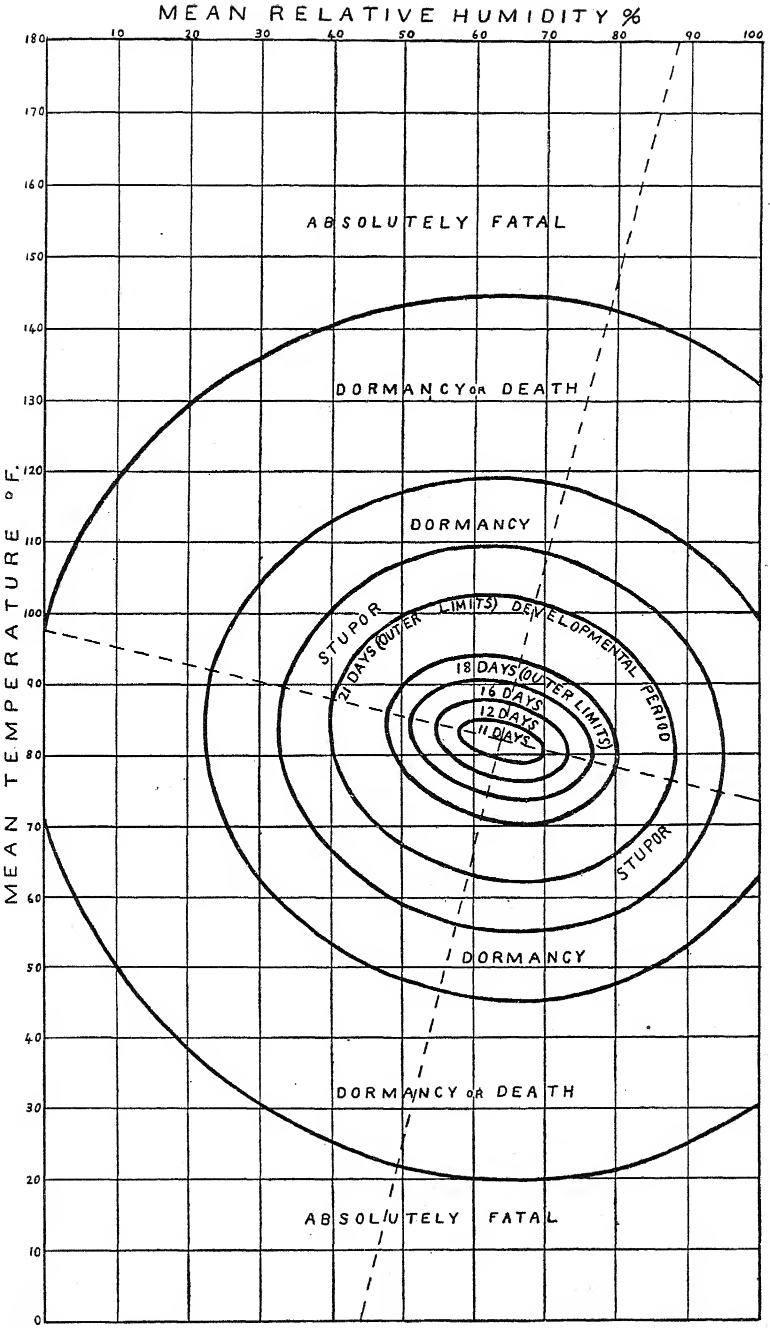



FIG. 2.—Relations of temperature and humidity to Cotton Boll Weevil activity. (After Pierce.)

place. For example, if the amount of body fluid be above the optimum, a dry atmosphere will remove the surplus and so speed up the rate of metabolism, whereas a saturated atmosphere, by impeding evaporation from the body surface, would slow down the rate of metabolism and thus prolong egg or pupal stages. Similarly, if the body fluid were just about the optimum, dry air, by reducing it below that point, would decrease the metabolism rate, whereas moist air, impeding evaporation, would permit the water-content of the insect to rise towards the optimum, and so increase the rate of metabolism.

Such a view, whilst applying of course only to insects which do not take in water and whose body fluid thus depends upon the water produced by tissue reactions, does afford some explanation of the discrepancies in the response of different insect species, or different stages of the same insect, to the same degree of atmospheric humidity. For example, laboratory experiments made by Headlee indicate that the rate of metabolism in pupae of the Bean Weevil (*Bruchus obtectus*) and the Angoumois Grain Moth (*Sitotroga cerealella*) varies *inversely* with the atmospheric humidity; in the adult of the former it varies *directly*, in the adult of the latter it varies *inversely*, with the humidity; in the larvae of both types the rate varies *directly*, and in the egg stages *inversely*, with the humidity.

The liability of some stages of an insect life-cycle to vary, in rate of metabolism, *directly*, and other stages to vary *inversely*, suggests that any alteration in duration of a stage may be compensated for by a corresponding alteration in the duration of a succeeding stage, so that the average length of life-cycle remains unaltered.

Thus Baumberger (1917) found that in the Oak Egger Moth (*Lasiocampa quercus*), when the length of the caterpillar stage was gradually reduced from the normal 245 days to 112 days by refrigeration methods and by selection of precocious larvae, the pupal stage always lengthened accordingly, so that the length of the whole life-cycle was always about the same.

There are many cases, however, where such a compensatory adaptation is lacking and where the duration of the life-cycle may be prolonged or even shortened somewhat by extreme atmospheric conditions. This is particularly the case with insects which under appropriate food and atmospheric conditions can breed all the year round. The life-cycle of house-flies and blow-flies, for example, is longer in temperate than in tropical regions.

Numerous interesting examples could be brought forward

regarding the toxic effect brought about by extremely high or low temperature or humidity upon an insect species. Thus Craighead (1920) asserts that, in the case of certain forest insects, solar radiation alone is sufficient to kill various species of beetles that infest timber. Species of Bostrychidae and larvae of *Chrysobothris* sp. which attack mesquite wood were killed if placed in direct sunlight. In timber, at the depth of half an inch, 45 per cent of the insects were killed inside two days; at three-quarters of an inch, 75 per cent were destroyed in a week, and 90 per cent within two weeks. The inner bark on logs exposed to direct sunlight was found to reach in certain cases a temperature sixty degrees above that of the outside atmosphere.

It is commonly supposed that severe winters destroy insect pests to such an extent as to limit the possibility of serious outbreaks during the following season; but according to a French observer, Feytaud (1919), such destruction is more acutely felt by predatory carnivorous insects than by phytophagous ones, so that the ultimate effect of an extreme winter upon insects is not apparently favourable to the agriculturist. Lepidopterous larvae and pupae can undoubtedly withstand temperatures below zero.

Such ability to withstand a low temperature may be associated to some extent with the habit of periodical hibernation indulged in by insects of temperate zones. If the insect, before hibernation or aestivation, loses 30 per cent of its gross weight by loss of water, as Tower (1917) asserts is the case with the Colorado Potato Beetle (*Doryphora decemlineata*), its tissues can possibly withstand more severe extremes of temperature than if the protoplasm were not thus condensed. Such a fact would explain the undoubtedly high mortality produced among insects by severe frost in late spring or following a spell of mild weather, such insects having probably safely endured more severe frost in late autumn or winter. Thus it is stated that larvae of the Codling Moth (*Cydia pomonella*) are killed by low temperatures if applied during mild weather in February, in spite of the general tolerance shown by Lepidopterous larvae to temperatures below zero.

It is not improbable, therefore, that there is some justification for the belief that the habit of hibernation may have resulted from the influence upon the species of recurring winter conditions, and that the habits of the insect itself have determined to what extent the habit has become rhythmical. Hibernation would seem to be a phenomenon lacking in the life-cycle of tropical insects, or in that of insects able to propagate whenever favourable conditions exist. It would seem,

however, that temperature is not the only factor conducive to hibernation. Many species commence to hibernate before any marked fall in temperature occurs. Tropical insects and non-hibernating insects cannot be induced to hibernate by application of low temperatures; they become torpid, it is true, but they regain their activity when the temperature is raised. Tower (1917) was able to keep the Colorado Potato Beetle in hibernation for eighteen months at a high temperature, if the atmosphere were sufficiently dry. A similar effect of drought has been shown to occur in autumn broods of the Hessian Fly (*Mayetiola destructor*). Such facts, namely, that extreme drought and extreme cold conduce towards hibernation, certainly support the possibility of this phenomenon being prefaced by a reduction of body fluid in the insect.

In studying the limitations of insects by climatic conditions, Hopkins (1919) has suggested, for the United States at any rate, the use of what he terms the "**Bioclimatic Law.**" That is to say, according to Hopkins, if the date of a periodical event, such as, for example, the date of the emergence of the first Hessian Fly brood of the year, be established for one particular locality, then a corresponding date for the same phenomenon in another district can be determined by calculating a variation which is at any rate of four days for each degree of latitude, five degrees of longitude, and four hundred feet of altitude. There may be slight errors in this computation, due to topographical differences, soil conditions, and weather variations, but the amount of such error is in direct proportion to the intensity of the controlling influences, which can be measured, therefore, in terms of days or the equivalent in degrees of latitude or feet of altitude with the computed date as a constant. In a similar way the geographical limits possible to the insect might be computed.

The Southern Pine Beetle (*Dendroctonus frontalis*) of the United States, for example, has two complete generations a year in the northern and highest limits of its range, but in more southerly areas may have five or more generations, the broods overlapping from late spring to early autumn. Remedial measures, consisting, generally speaking, of removal and destruction of infested bark, should be undertaken during the period when all stages of the beetles are to be found in the tree, that is to say, during the period between the end of autumn and the commencement of spring. This period varies according to latitude and altitude, commencing in September in the north and higher altitudes and in December in the south towards sea-level, ending about the middle of May in the north, about the end of February in the south. The period

of control possibility, in fact, can be calculated quite accurately from climatological data, and Hopkins would seem to have founded his generalisation upon data derived chiefly from observation of this type of insect. Whether the Bioclimatic Law is of general application to other types of insects and to other countries remains to be settled.

In the United States, this principle is being adopted to determine the dates of sowing wheat in areas infested by the Hessian Fly (*Mayetiola destructor*). The general method of avoiding Hessian Fly damage in the winter wheat regions is late sowing in the autumn. The autumn brood of flies appears and disappears within about a week, so that if the date of emergence, being controlled primarily by climatic conditions and secondarily by weather, soil, and topographical influences, can be calculated, a " fly-free " date for the sowing of wheat can be recommended for any particular district.

# CHAPTER III

## DISEASE

THE various diseases produced in insects by micro-organisms may for convenience of description be distributed among four classes, these being :

1. Diseases caused by Fungi.
2. Diseases caused by Bacteria.
3. Diseases caused by Protozoa.
4. Diseases of unknown origin, but suspected to be caused by micro-organisms.

The various attempts to utilise such diseases as a method of insect control date back, in the case of fungus diseases, to the middle of last century, but in the case of bacterial diseases are naturally of more recent date, certainly within the last twenty years. Generally speaking, such efforts have so far been disappointing in the results achieved. It would seem as if insufficient attention had been paid—

(a) To the *receptivity* of the insect, to the fact that an insect may be particularly susceptible to the disease at one particular stage of its life-cycle and resistant at others ;
(b) To the *optimum conditions* for the particular diseases under propagation ; in the case of fungus diseases, for example, damp, cool weather is usually essential to the production of an epidemic, so that artificial dissemination of spores during a dry, warm season will therefore be useless ;
(c) To the conditions which influence the virulence of the micro-organism ;
(d) To the exact way in which the parasite attacks the insect ;
(e) To the necessity for the optimum activity of the disease coinciding with the optimum activity of the insect which is to be attacked.

### Fungus Diseases

A considerable number of fungi are known to bring about pathological conditions among insects. In the lower fungi,

the Zygomycetes, saprophytic generally upon decaying animal or vegetable tissues, include two groups, the Mucorales and the Entomophthorales, which are of particular entomological importance, the latter group in fact being exclusively parasitic upon insects. Among the higher fungi, the class Ascomycetes includes the group Laboulbeniales, almost exclusively parasitic upon Coleoptera, and also many entomoparasitic representatives among the groups Hypocreales, Sphaeriales, and Erysiphales.

The parasitic fungus may affect the insect host in various ways:

1. It may live on the integument without either seriously damaging the underlying tissues, or injecting toxic substances into the system of the host.
2. It may pierce the chitin and destroy the underlying tissues.
3. It may send a branching mycelium into the body, choking up the tracheae and causing suffocation. In the case of *Botrytis* and *Cordyceps*, the tissues of the host become replaced by a secretion, and a characteristic mummification, the so-called "Muscardine condition," of the insect is thus brought about.

The Entomophthorales include two important genera, *Empusa* and *Entomophthora*, and, of slightly lesser importance, *Tarichium* and *Lamia*.

*Empusa muscae*, Cohn, has long been known as a parasite of various Muscid and Syrphid flies, appearing under damp autumnal conditions as a halo-like mould enveloping the fly and ramifying throughout its tissues. The spores have been supposed to work their way into the fly through the surface of the abdomen, but some experiments by Hesse (1913), who has infected houseflies by feeding them upon the culture of the fungus, seem to indicate that zygospores swallowed in syrup by a fly are thrown off as conidia, the fungus thus entering the fly *via* the alimentary canal and probably germinating in the crop.

There seems to be a possibility of *Empusa muscae* and the saprophytic fungus *Mucor* turning out to be biological forms of one species. Both Hesse and later observers, such as Bernstein (1914), have repeatedly cultivated material from flies, undoubtedly killed by *Empusa*, upon slices of sterilised yolk of egg, and obtained only *Mucor racemosus*; further, flies fed upon a syrup containing spores of *Mucor hiemalis* and *Mucor racemosus* died with the usual signs of *Empusa muscae*. Other observers, such as Ramsbottom (1914), dispute these evidences of polymorphism, and suggest that a mycelium of *Mucor* appearing in a culture of *Empusa* might have arisen from spores of *Mucor* enclosed by a cluster of the larger *Empusa* spores.

Several other species of *Empusa* are known : thus *Empusa plusiae*, Giard, attacks Noctuid larvae ; *Empusa planchoniana* attacks Aphids.

Of the various species of the allied genus *Entomophthora*, one species, *E. aulicae*, gives promise of being useful as a practical method of insect control. Speare and Colley (1912), working in the Brown-tail Moth area of Massachusetts, claim to have obtained an epidemic of 60 per cent average mortality among Brown-tail larvae by suspending artificially infected larvae in paper bags among the clusters of caterpillars.

Of the various Ascomycete fungi responsible for insect diseases, the best-known genus is probably *Cordyceps*, better known in its conidial stage, the so-called *Isaria*.

*Isaria densa*, the conidial stage of *Cordyceps entomorhiza*, was described by Giard so far back as 1893 as epidemic upon cockchafer larvae, and prevalent also upon Sphingid caterpillars, Noctuid caterpillars, silkworms, and other insects. Giard found that cockchafer larvae were readily infectable, and various methods of large-scale propagation were described by him—of artificially infected larvae, dissemination of cubes of potato upon which the fungus had been cultivated, and other similar processes. The efficacy of artificially propagating this fungus to control this serious pest has not, however, been definitely established, and no method of so doing can be seriously recommended.

The value of such fungus epidemics in particular years when conditions are favourable to the fungus cannot be denied. Thus, according to a Norwegian observer, Sopp, *Cordyceps norvegica*, common in the soil of Norwegian forests, reduced to harmlessness in 1907 that serious caterpillar pest of conifers *Dendrolimus pini*.

In France the vine moth pupae, *Polychrosis* and *Clysia*, are subject to attack by a fungus originally known as *Isaria farinosa* after its discovery in 1893 by Sauvageau and Perraud, but now known as *Spicaria farinosa*, var. *verticilloides*. The fungus occurs in the soil of vineyards, and the French practice of heaping up earth round the vine stocks is especially favourable to its propagation, the consequent mortality among vine moth pupae sometimes reaching to 85 per cent. In those districts where this practice of heaping up is followed, the losses from vine moth would appear to be slight.

The earliest attempts to induce an epidemic of fungus disease were undoubtedly those made in U.S.A., particularly by Forbes in Illinois, 1888–1896, in the fight against the Hemipterous cereal pest, the Chinch Bug (*Blissus leucopterus*). The fungus which was the subject for experiment was *Sporo-*

*trichum globuliferum,* known since 1865 to cause naturally occurring outbreaks among these insects. Similar epidemics are known also as a result of the activities of a species of *Entomophthora, E. aphidis.*

Much experimental laboratory and field work has been carried out, not only by Snow and Forbes, but by more recent workers, but the fact remains that all the States whose officers took part in these fungus experiments have discarded this method of chinch bug control. It seems certain that epidemics of fungus disease only occur when excessive numbers of chinch bugs coincide with a considerable amount of wet but hot weather. So widespread is the fungus distributed throughout the soil of the chinch bug areas, that under these conditions such epidemics will occur whether aided by artificial means or not, whereas in dry or cold weather such epidemics neither occur naturally nor can be induced to occur by artificial methods.

*Sporotrichum globuliferum* was introduced into Algeria in 1892, and is asserted by several trustworthy observers to have provoked several epidemics among flea beetles of the genus *Haltica.* Debray, in 1894, carried out experiments in the artificial contamination of these with eight different species of fungi; results were positive for five species, in particular for *Sporotrichum globuliferum,* but although the adult *Haltica* is readily infected the larvae seems fairly resistant.

Vaney and Conte (1903) cultivated the fungus *Botrytis bassiana* upon silkworms, and, by contaminating the leaves of the vine with a spore emulsion, claimed a considerable degree of infection and consequent mortality among the Haltica larvae.

In spite of these results, however, the spore dissemination of *Botrytis* has not been generally adopted as a method of flea-beetle control. The view of Vaney and Conte that spore infection took place *via* the alimentary canal has been vigorously opposed by Picard who, from laboratory experiments upon the potato-moth caterpillar *Phthorimaea operculella* with spore emulsions from several species of fungi, asserts that infection of the caterpillar occurs by actual penetration of conidia spores through the skin. Such an assertion is of considerable importance, bearing as it does upon the question of the utility of spraying leaf-sucking insects with spore emulsions. If Picard's view is correct, then the use of fungus-spore emulsions against Aphids is justified.

In Florida, where an abundant rainfall and a hot atmosphere favour fungus development, extensive attempts have been

made to utilise naturally occurring fungus diseases of Scale insects and Whitefly (*Aleurodes*) in citrus groves. The more important species of fungus which attack *Aleurodes* are the Brown Fungus (*Aegerita webberi*), the Red Fungus (*Aschersonia aleyrodis*), and the Yellow Fungus (*Aschersonia flavocitrina*). These fungi have been applied by the spore-spraying method. From twenty-five to thirty leaves having an abundance of pustules on them are allowed to soak from five to ten minutes in a pail of water, the mixture strained and then sprayed upon the underside of the leaves of the plant, preferably during the summer rains.

Fungi attacking various Scale insects, such as the Red-headed Fungus (*Spaerostilbe coccophila*) and the White-headed Fungus (*Ophionectria coccicola*), seem better propagated by tying pieces of fungus-bearing material to the infected trees.

On the whole, the results obtained are regarded as satisfactory, and the Plant Board of Florida grow and supply pure cultures of these fungi, with instructions for applying them to trees, although opinions vary as to whether the methods bring about any increase in the efficacy of a fungus already established (Rolfs and Fawcett, 1913; Nowell, 1915).

Glaser (1915) asserts that even where only small quantities of fungus are already in a grove, there is no certainty that from three to six applications of fungus spores in water suspension will increase the amount of infection to any great extent.

### Bacterial Diseases

Diseases brought about in insects through the agency of bacteria have been little studied. Forbes in 1882 had, it is true, suggested that large numbers of a micrococcus in the gut of diseased chinch bugs might prove to be the cause of disease, but further investigation proved their occurrence to be normal.

A Russian observer, Krassilstschik, had also, in 1892, described two diseases of cockchafer larvae in Central Russia:

1. *Graphitosis*, so called owing to the powdered graphite appearance of dead larval victims, and caused, according to the observer, by *Bacillus tracheitis sive graphitosis*.
2. *Septicaemia*, characterised by a brownish discoloration of the skin, and caused by *Bacillus septicus insectorum*.

Yet in spite of much experimental work by this observer, it cannot be said that the possibility of bacterial disease as

a factor in insect control was seriously considered by the economic biologist until the communications of D'Herelle to the Académie des Sciences in 1911 and 1912 became known.

D'Herelle drew attention to a severe epidemic among the hordes of the Mexican Locust (*Schistocerca pallens*) in Yucatan in 1911, and he associated it with the presence of a cocco-bacillus in the blackish fluid contents of the alimentary canal of insects attacked. That this is the causative organism seems indisputable.

It has been shown by D'Herelle and by later investigators that:

(*a*) the virulence of the disease may be increased by passage through a succession of hosts, but that
(*b*) it becomes diminished in successive cultures.

D'Herelle's method of culture is first to pass the bacteria through the bodies of many grasshoppers in rapid succession. The actual number of passages varies with the species of insect: for example, with *Schistocerca americana* D'Herelle used twelve hosts in succession; in each case the insect was injected with a diluted extract from the intestine of the preceding host. A strain of bacillus was produced eventually that would kill within three hours after injection. At this stage the insect was dried well, pulverised, and sealed in tubes, or else the intestinal extract was cultivated on artificial media, such as, for example, 5 grams of peptone, 5 grams of meat extract, 5 grams of salt, and 1 litre of water at normal temperature. Such a culture can be used within ten to eighteen hours after introduction of the bacillus. It is distributed over the infested area of spraying, one litre sufficing for two acres; the insects are believed to become infected by eating contaminated leaves, or diseased corpses of their fellows.

The pathogenicity of such cultures in the laboratory is indisputable, but opinions as to their efficacy in the field are conflicting.

D'Herelle postulated as factors necessary to success:

(*a*) Cannibalism and migratory habits in the host;
(*b*) Dense infestation;
(*c*) Absence of related bacteria that might have an immunising effect; even as it is, some 25 per cent may recover and become immune;
(*d*) No excess of normal food;
(*e*) High temperature and absence of excessive rains.

Glaser, who has made a systematic study of *Coccobacillus*

*acridiorum*, would add a sixth factor, the necessity for purity of the culture.

Speaking generally, field experiments upon species of *Schistocerca* have been very effective. It was the wholesale destruction of *Schistocerca pallens* in Yucatan in 1911 that first attracted the attention of D'Herelle to the subject. Similar results he claims to have obtained experimentally in Tunisia in 1915 against *Schistocerca peregrina*, and similar successes against the same species in Algeria and Morocco are claimed by other workers. Against genera of less cannibalistic habits, the disease seems to be less successful. Thus, non-success is reported with the Philippine Locust (*Pachytylus migratoroides*), with the Argentine Locust (*Schistocerca paranensis* and *Caloptenus sp.*), with *Stenobothrus*, *Melanoplus*, and *Xiphidium*, all three non-migratory and non-cannibalistic locusts of Eastern Canada.

Lounsbury, against *Zonocerus elegans* in South Africa, found field experiments with the bacillus culture to be of no effect, but attributed his failure to heavy rains and to cessation of feeding by the mature insects.

Very often, as Glaser has shown, failure may be due to the use of impure cultures, or even wrong cultures such as the pathogenic but irrecoverable *Bacillus poncei*.

Some authorities assert that *C. acridiorum*, or the group to which it belongs, is a normal inhabitant of the intestine of locusts, and therefore, whilst probably pathogenic when injected into the body cavity, cannot be expected to be so when merely ingested.

The discovery of *Coccobacillus acridiorum* has attracted much attention to this phase of insect pathology, and other coccobacilli have been recorded from different species of injurious insects, especially from Macrolepidoptera. In fact, one might safely assert that the bacterial flora of insects is scarcely surpassed in richness and variety by that of Vertebrates; the most commonly occurring pathological consequence of bacterial action upon insects, however, is Septicaemia, and, in fact, the bacteria of insects never seem to show such a specificity for the host-tissues as is shown by such parasites of man as *Meningococcus* and *Gonococcus*.

Interesting experiments regarding the immunity of insect larvae to bacteria which are pathogenic to man and higher animals have been made by Metalnikoff (1920), who, using the larvae of the Bee Moth (*Galleria mellonella*), finds that they are completely immune to a group of organisms including the various agents of tuberculosis, diphtheria, tetanus, etc.; are less immune to the organisms of plague, fowl cholera,

Asiatic cholera, typhus, anthrax, etc.; and are very susceptible to *Bacillus coli communis*, *Bacillus pyocyaneus*, *B. prodigiosus*, *B. subtilis*, *B. proteus*, etc. That is to say, whilst susceptible to saprophytic bacteria, these insect larvae are immune to bacteria which are highly pathogenic to the higher vertebrates. The destruction of these latter organisms in the larva is asserted, by Metalnikoff, to result from active phagocytosis, the micro-organisms being rapidly ingested and destroyed by the blood cells, much as in higher animals; but Paillot in a series of recent articles has put forward a different explanation.

If, for example, a caterpillar of the genus *Agrotis* be inoculated with a fresh emulsified culture of *Bacillus melolonthae-non-liquefaciens*, the animal quickly dies from septicaemia although a certain amount of phagocytosis occurs. If, however, the culture be two or three months old, the caterpillar not only resists it but appears rendered immune to a fresh culture injected within a succeeding period of twenty hours. The resistance is apparently due to a colloidal reaction between the blood and the organisms, which leads to their transformation into a granular condition. Paillot asserts that this granular transformation is not brought about in any way by the action of the blood cells, at any rate of those cells, the micronucleocytes, which ingest bacteria; so that the degree of resistance offered by an insect to micro-organisms is dependent not upon any variation in phagocytic action, but upon a physico-chemical modification of the organism, brought about by the blood, and whose intensity varies according to the insect individual, the character of the micro-organism inoculated, the temperature, and similar factors.

### Protozoan Diseases

The Protozoan organisms which may bring about epidemic disease in insects have not been studied to the same extent as have the entomogenous fungi and bacteria, but the few that we know most about are members of the Sporozoa, the predominantly parasitic division of this phylum.

The earliest known Protozoan disease of insects to be investigated was undoubtedly *Pebrine*, an epidemic disease of the Mulberry Silkworm (*Bombyx mori*). The occurrence of small, ovoid, shining, and motile bodies in the tissues of the infected caterpillars was long believed to be merely a symptom and not the causative agent: by the Italians they were regarded as degenerate tissue cells; by Guérin Meneville as Haematozoa; by Nageli, whose suggested nomenclature—*Nosema bombycis*—

still holds good, as Schizomycetes; by Lebert as unicellular Algae (*Panhistophyton ovatum*).

Pasteur, who investigated the disease in 1864 and discovered the method of infection, regarded the ovoid bodies as neither animal nor vegetable in nature, but analogous to the granulations of cancer cells or to pulmonary tubercles.

Balbiani, though at first of the opinion that these bodies were fungus spores, recognised in 1866 their Protozoan nature, and created for them the order Neosporidia. The life-cycle was finally made clear by Stempel, 1909.

The life-history begins with small uninucleate amoebulae, at first free in the alimentary canal, but later wandering into the body tissues generally. These wanderers penetrate into cells, grow larger and assume an ovoid shape; they may multiply by binary or multiple fission until the host cell is used up, whereupon a final generation is produced which gives rise each to a single spore.

Pasteur showed that caterpillars may become infected in two ways:

1. They may ingest leaves contaminated with spore-containing faeces from infected caterpillars.
2. The egg may contain dormant spores, so that the caterpillar is hatched in an infected condition.

The life-history of *Nosema apis*, associated with the Isle of Wight Bee Disease and believed until recently to be the sole causative agent, is similar.

Krassilstschik (1886) described a deadly epidemic among caterpillars of *Phylactaenodes sticticalis*, a little moth very abundant in Central Russia, apparently brought about by a new genus of Microsporidia that he termed *Microklossia*. There would seem to be an indication of egg-infection similar to the so-called "hereditary infection" of silkworms. *Microklossia* has been recorded also as heavily infesting *Mamestra oleracea*, the Cabbage Moth, in Russia, 1902.

Leger, 1907, described a new Myxosporidian in the genital organs, fat-body, and blood of a Tenebrionid beetle, *Scaurus tristis*, occurring in Algeria, which brings about parasite castration in its host.

### Diseases of Unknown Origin

In addition to the pathological conditions that may be produced in insects by the activities of fungi, bacteria, and Protozoa, there is in addition a class of infectious diseases whose causative organisms are yet unknown; the diseases,

however, agree with one another in being associated with the occurrence of polyhedral bodies in the cell nuclei of the insect victims. These intrusive bodies were first described by the Italian, Cornalia, in 1859, who observed them in the blood of diseased silkworms. In a caterpillar suffering from this type of disease, the tissues degenerate and a smear will show, in addition to fat globules, urates, cellular debris, hairs and pigment granules, myriads of bodies varying in size between one to six microns in diameter and in shape approximating generally to a polyhedron with rounded angles.

In "Grasserie," the so-called jaundice of silkworms, the granules are almost perfect octohedra, but in the "Wilt Disease" of Gipsy Moth larvae a geometrically symmetrical outline is never observed (Fig. 3). They seem to have a central portion denser than the periphery, to be composed of concentric layers, and, although cracking readily into a number of pieces, seem to be tough and elastic in their nature rather than brittle as would be inorganic crystals.

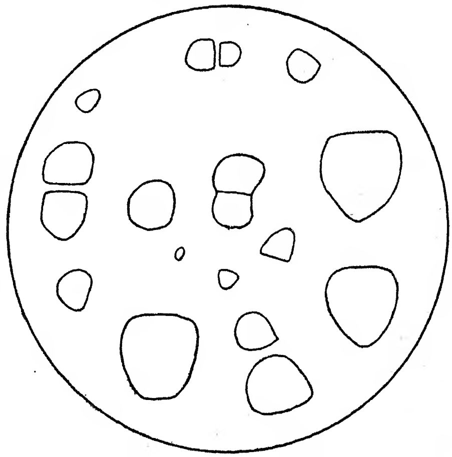


FIG. 3.—Polyhedral bodies as seen in smears of wilted caterpillars. (From Glaser.)

Opinions as to the significance of these bodies vary. The old view that they were actual causative organisms is not now held, nor has the Protozoan view of Bolle received confirmation. The more general opinion of recent observers is that they are reaction products, belonging possibly to the nucleoproteins.

At the same time, one must admit that no pathogenic organism has yet been found, although several attempts to demonstrate a bacterial origin for this group of diseases have been made.

Prowazek, in 1907, asserted that he had been able to infect caterpillars by injecting a filtrate of emulsified diseased tissue containing neither bacteria nor polyhedral bodies, and he suggested that the causative organism was a filterable virus, that is to say, minute enough to pass through a diatomaceous filter; such minute organisms, he suggested, disintegrate the nuclear material of certain tissue cells, and the polyhedral

bodies are synthesised from the disintegrating proteins. It must be pointed out, however, that of thirty diseases known at present to be produced by filterable viruses, only one, Sacbrood, occurs in insects, and in no case of these are polyhedral bodies known to occur.

Fischer, looking to metabolic disturbance as the cause of these diseases, claims that caterpillars fed on foliage that had been soaked for some time in water showed a condition identical with Wilt Disease, and that, in nature, defoliation of a tree brings about a condition of the roots which reacts on the foliage of the succeeding year and affects the caterpillars.

Acting upon this suggestion, Reiff in U.S.A., has carried out large-scale experiments in the artificial propagation of Wilt Disease among Gipsy Moth larvae. The disease is produced in the laboratory by feeding caterpillars upon leaves that have been soaked in water for three or four days. The contaminated caterpillars are placed in little bags and suspended in the trees. Great success is claimed, but this possibility of transmission of the disease has been opposed by the German observer Escherich and by Glaser in America, who both assert that caterpillars can only become infected by actual ingestion of contaminated foliage.

In Egypt, in 1910, a disease termed "Grasserie" broke out spontaneously amongst caterpillars of the so-called "Cotton-worm" (*Prodenia litura*), in reality a Noctuid moth, and caused great natural mortality. In this case, experiments by Dudgeon (1913) seemed to indicate that the disease may be successfully propagated by spraying the cotton plants with water containing infected larvae, so that the foliage became contaminated.

That these polyhedral diseases are readily transmissible seems certain, but until the real cause of them is known, and until more precise facts concerning their etiology and transmissibility are established, little success can be expected from attempts to utilise their activities as a method of insect control.

## CHAPTER IV

### PARASITES AND PREDATORS

It is not easy to draw a definite line of division between the terms *parasite* and *predator*. Both are organisms which live at the expense of another. The parasite, however, strictly speaking, obtains its nutriment from its host in an indirect manner; the predator supports itself in cruder, more direct fashion: it is the difference between the thief and the robber.

The parasite may be a sucker of blood or of coelomic fluid, or may absorb the fluid products of its host's digestive powers, but a true parasite does not attack the vital host tissues. It may live throughout its existence within its host, or may simply attain full size and quit the host, without in either case causing fatal lesions. Death of the host, when it does occur, is due rather to exhaustion, to deficiency of those nutritive fluids abstracted from it by the parasite, or to general metabolic disturbance resulting from excessive activity or multiplication of the parasite, rather than a result of definite tissue injury. The more completely adapted the parasite be to its host, the longer will be its connection with it, and the less its liability to injure it. Tolerance of a parasite by a host organism, therefore, would seem to imply an interrelationship of long standing: an organism that kills its host is, comparatively speaking, a newcomer to the ranks of parasitism; it has not yet attained the status of a true parasite; it is just as much a predator as is the organism which lives by violently assaulting and immediately devouring weaker forms of life.

Insect structure, it must be pointed out, is peculiarly favourable to the presence of true internal parasites. An insect larva is a voracious feeder, its alimentary canal is usually long, there is generally a mass of reserve food-stuff in the form of "fat-body," and the body cavity differs from the body cavity of most other animal groups in being a *haemocoele*, a blood space, a comparatively spacious cavity containing a rich broth of nutritive substances resulting from food digestion.

The variety of parasites upon the insect economy is consequently very wide. There is, for example, probably a much richer Protozoan, Helminth fauna, and Bacterial flora, than has yet been described. Present knowledge, however, of the parasites of insects, though extensive, concerns chiefly parasites which are themselves insects, and it is precisely among Insectan parasites that true parasitism seems as yet to have evolved but rarely.

Even if we accept the usual entomological conception of parasitism, and regard as a parasite an organism that can subsist upon *one*, or at most two, host individuals, and a predator as an organism that requires a *succession* of host individuals, we still find a large number of forms which cannot be placed definitely in either class but oscillate from one side of the border line to the other. For example, Smith (1919) quotes the case of the female Chalcid (*Scutellista cyanea*), which deposits its egg beneath the adult Black Scale (*Saissetia oleae*). The resulting larva feeds upon the eggs of the host, and requires several hundreds to complete its development, although it always matures beneath a single scale.

Few cases are known where the insect really does play the role of true parasite, although possibly the phenomenon occurs more commonly among insectan parasites than has been established, and the fact remains that, in the great majority of parasitic insects whose life-histories are known, indirect nutrition occupies only a portion of the larval period. This method of feeding may, as in Pipunculidae, occupy the greater part of larval life, terminating when the parasite larva attains its maximum size, whereupon it devours its host; but more generally, the period of indirect nutrition is short, restricted often to the first stage of larval life-history. In subsequent stages the larva may confine its tissue-devouring proclivities to the less vital portions of its host, so that the latter may still go on living until the parasite larva is full size, but nevertheless that larva is feeding, not as a true parasite but, biologically speaking, as an internal predator.

Thus, although to the entomologist any carnivorous insect that limits itself to one host individual ranks as a parasite, such an insect may be only parasitic for a very brief period and internally predatory for the rest of the larval existence. It is obvious, therefore, that the shorter this period of true parasitism is, the more effective from an economic standpoint will be the attacking insect.

When an insect lives at the expense of another, its growth is of course directly dependent upon the amount of nutrition it can obtain. A true predator cannot necessarily be much

less in size than its host, unless it habitually attacks the egg or pupal stage; in fact, in most cases a predatory insect is as big as or bigger than its prey in size. It cannot possibly, therefore, derive sufficient sustenance from one host individual to tide it through its life-cycle, even if the individual be exploited to the uttermost; a succession of host individuals will be necessary. In order to obtain the requisite number of victims the predator will have to be very active, as are predatory beetles and their larvae, or else the host individuals will have to be very sluggish and gregarious, as are the Aphid victims of predatory Syrphid larvae.

Now, activity puts a premium upon rapidity of development. Active predators such as ground beetles have necessarily a long life-history. The excess of anabolism over katabolism is small, so that development to maturity is comparatively slow. Some predators, Syrphid larvae, have a fairly short life-history, it is true, but they are less active and have usually an abundant supply of sluggish victims.

On the other hand, if the invading organism becomes adapted to utilise the nutritive juices only of the host, it can subsist for a long period upon one host individual, providing that the latter feed continuously for a sufficiently long period, be not vitally injured by the parasite, and be sufficiently large to enable the parasite to attain full growth within it. Such ideal conditions occur in many groups of insects—for example, the Orthoptera, the Hemiptera, the Noctuid Lepidoptera; and it is significant that it is from these groups that the few cases of true parasitism among insects have been recorded.

In the higher groups of insects, however, the feeding period is often comparatively short and confined to the larval stage only, or the host insect is very readily affected by the activities of the internal parasite and ceases to feed; frequently, too, the host individual is not sufficiently large to permit the attainment of full growth of the parasite.

In such cases, indirect nutrition is interrupted and the parasite becomes a predator, completing its development at the expense of the solid tissues of its host until only the empty skin of the latter is left.

If the size of the host be small in proportion to that of the fully-grown parasite larva, or if several such larvae occur, the predatory phase may be carried through on the external surface of the host.

This view, namely, that the so-called parasite of the entomologist is, in the vast majority of cases, merely a parasite in its earliest stages only, and is afterwards a predator, may seem to be contradicted by the well-known fact that the larvae of

Hymenoptera Parasitica, or of so-called parasitic Diptera, usually show in their earliest stages more evidence of locomotor organs than in later stages. Thus an ordinary Staphylinid beetle larva, an undisputed predator, starts its life well equipped with limbs and retains them throughout each larval stage. On the other hand, *Aleochara bilineata*, a Staphylinid larva which lives within the puparium of the Cabbage Root Maggot, is described by Wadsworth (1915) as hatching from the egg as a typical free-living campodeiform Staphylinid larva which enters the puparium of the root-maggot, feeds upon the pupa therein, and at the first moult becomes eruciform, that is to say, loses its legs.

It must be pointed out, however, that, although a degeneration of locomotor organs is frequently understood to be a characteristic of a parasitic mode of life, the term parasitic in this connection merely implies a mode of life where activity in obtaining food is reduced to a minimum ; such degeneration is not confined to parasites ; it is found in larvae which are coprophagous, saprophytic, or in the larvae of social insects ; the presence or absence of limb structures, therefore, cannot be accepted as a criterion in deciding whether an endophagous insect larva is a parasite or a predator.

Examples of parasites and predators upon insects may be obtained from almost every group of the animal or vegetable kingdom. There is, for example, a very extensive Protozoan fauna, and Bacterial and Fungal flora, of insects, the economic possibilities of which have been as yet scarcely investigated. There is even a good number of insectivorous flowering plants (*Drosera*, *Sarracenia*, etc.). Among the Flatworms, many parasites of insects occur. Tapeworm larvae are particularly dependent upon insect hosts. Thus the Cat tapeworm (*Dipylidium caninum*) undergoes its cysticercoid asexual phase in the flea *Pulex serraticeps*, and the louse *Trichodectes canis*. The larval stage of the Pigeon tapeworm (*Drepanidotaenia infundibuliformis*) has the house-fly *Musca domestica* as host.

Many examples of Nematode worms are known to parasitise insects. *Habronema muscae*, for example, is known to occur as a larval stage in the proboscis and head of *Musca domestica*, the adult living in the stomach of the horse. The larvae are able to escape from infected flies when the latter settle upon mucous surfaces such as the mouth, nose, or eyes. If the larvae escape into the mouth of the horse they will reach the stomach, where they develop to maturity after undergoing a series of moults. The larvae that are deposited elsewhere than in the mouth die off, but may first set up inflammation resulting in a granuloma or perhaps even swamp cancer (Johnston, 1920).

In Italy 20-30 per cent of flies are said to be infected, but in Great Britain the percentage would seem to be much less. The flies do not seem to suffer any ill effects.

The Nematode family Mermithidae is exclusively parasitic in insects. *Sphaerularia bombi*, for example, burrows as a fertilised female into the body cavity of a queen humble-bee (*Bombus*) when she is seeking winter quarters, and so injures the reproductive organs of the bee as to render her sterile.

The species of *Gordius* are almost exclusively parasites of insects. The Acanthocephalan worms, parasitic within vertebrates, have a larval phase very often confined to an insect host. Thus *Echinorhynchus gigas* from the pig has as its larval habitat the body cavity of larval chafer beetles, *Melolontha* and *Cetonia* in Europe, *Lachnosterna* in the U.S.A.

Among Arachnida, the scorpions, spiders, chelifers, and camel-spiders are predators upon insects, and very many mites are external parasites upon them.

Speaking generally, however, the great majority of parasites, using the term in its entomological sense, are themselves insects, and the great majority of predators are also insects or belong to the Vertebrata. Within the class Insecta, several families of Petiolate Hymenoptera are almost exclusively parasitic upon other insects, and are grouped together, in fact, as Hymenoptera Parasitica. Of these families, the Proctotrypidae and Chalcididae are large families of minute insects of various parasitic habits but containing the majority of egg-parasites. The Ichneumonidae and Braconidae are larger insects, attacking particularly the larger types of insect larvae. The Chrysididae or Ruby Wasps frequent the nests of Solitary Wasps, and there are Parasitic Bees which live at the expense of Solitary Bees and Social Bees.

Amongst Diptera, the family Tachinidae is exclusively parasitic, and chiefly so at the expense of other insects. Numerous other families, such as Bombyliidae, Nemestrinidae, Pipunculidae, Cyrtidae, Conopidae, Anthomyiidae, Sarcophagidae, Muscidae, Braulidae, are also more or less parasitic in habit.

Among Coleoptera, the Mordellidae, Cantharidae, and Stylopidae are parasitic upon other insects, particularly upon Solitary Bees and Wasps.

The chief predators upon insects are either insects themselves—particularly the Coleopterous families Carabidae, Staphylinidae, and Coccinellidae, and the Wasps,—or they are Vertebrata. Freshwater fishes are largely insectivorous; Amphibia and Lacertamorphous reptiles largely so; the great majority of birds also depend upon insects, and amongst Mammals the orders of Insectivora (mole, hedgehog, shrew),

Edentata (anteaters and armadilloes), one division of bats, and the great majority of lemurs and monkeys, depend largely upon a diet of insects. In Barbadoes, the only species of freshwater fish in the island is a small Cyprinodont known popularly as the "Millions" fish, technically as *Girardinus poeciloides*; this fish feeds very largely upon mosquito larvae, and is undoubtedly of very great value as a destroyer of mosquitoes. Attempts have been made, therefore, to introduce this fish into West Africa *via* London, but without marked success. There are, however, several species closely related to, and of similar habits to, *Girardinus*, already present in West Africa—for example, *Fundulus* and *Haplochilus*; so that little would be gained by introducing *Girardinus*, particularly as it would have much more severe competition than in its native habitat.

### The Artificial Introduction of Parasites

The great increase in the numbers of an insect when introduced into an area where the factors which normally limit its abundance are absent has long been noted, and of these factors the one that plays the most effective part would seem undoubtedly to be the presence of parasites. The recognition of the importance of this factor has naturally brought about many attempts on the part of economic entomologists, to restore the disturbed balance of nature by the importation of parasites or natural enemies of the introduced insect from its original home, if such could be determined.

Many such attempts are now on record, and their results are somewhat at variance. The success of an introduced enemy against an insect pest cannot, of course, be reasonably expected unless it be certain that a region of the world exists where the enemy really does so control this particular insect pest that from an agricultural standpoint it is harmless. Non-recognition of this principle has been the cause of many disappointing failures in parasite introduction. A very early attempt by Riley, in America, to check the introduced Cabbage White Butterfly (*Pieris rapae*) by the introduction of its European Braconid parasite, *Apanteles glomeratus*, was doomed to failure from the outset, since the parasite is unable to control the butterfly even in its original habitat.

It may be asserted, in fact, in the light of experience gained from such attempts, whether successful or not, that the selection of a suitable natural enemy is not so simple a matter as was formerly supposed, and that the possibility of successful introduction and acclimatisation depends upon

thorough consideration of each of a complex of factors, the more important of which can now be discussed.

In the *first* place, the parasite or predator should be *capable of outnumbering its host.* Such a condition may result:

(*a*) From an actual greater number of eggs laid by the parasite than by the host. In such a case, the benefit derivable from this superiority in fecundity would be applicable only in the case of parasites that can exist in numbers within one host—Chalcididae, for example.

(*b*) From the habit of *polyembryony*, where, although only one egg may be laid, the ensuing larva by a process of asexual reproduction or budding may give rise to a large number of larvae.

(*c*) From a more rapid life-cycle and a consequently more rapid sequence of generations than the host. Any advantage so gained will be dissipated, from the economic standpoint, if the parasite be polyphagous—that is to say, if it attacks a wide variety of hosts.

(*d*) From a higher proportion of females than males, or from actual parthenogenetic habits. Shevirev (1913) asserts that in the case of *Pimpla instigator* and some other species of Ichneumonidae the imagoes that emerge from large Lepidopterous pupae, from those of Hawk Moths (Sphingidae) for example, are females, and that those that emerge from small pupae, pupae of *Pieris* for example, are males. Whether the female can adjust to the nutritive conditions the kind of egg she lays seems uncertain.

In the *second* place, the parasite should be specific in its action, should confine itself to one particular species of host.

Among parasitic insects various phases of host selection can be distinguished.

There are, for example, parasitic species which attack indiscriminately eggs, larvae, or pupae of a wide range of unrelated host species. Thus the Chalcidid genus *Eupelmus* attacks both eggs and larvae of numerous host species belonging to six natural orders of insects. This phase is probably uncommon. Of all the numerous parasites of the Gipsy Moth and the Brown-tail Moth recorded by the Gipsy Moth Commission, from Europe, America, and Japan, not one was found to attack both eggs and larvae.

Then there are cases of a parasite, or a group of parasites, which confines itself to some particular stage of the insect life-cycle but still remains indiscriminate in its choice of host species. Thus the Chalcidid genus *Trichogramma* attacks the

eggs of insects belonging to four orders; the members of the Proctotrypid family Scelionidae are all egg parasites.

Then again, a parasite or a parasitic group, whilst still polyphagous, may confine itself to some particular insect order. The Proctotrypid family Alysiidae confines itself to Dipterous larvae, the Braconid sub-family Aphidiinae is parasitic upon Aphides.

Finally, there are the cases where the parasite confines itself to one particular host species.

The relationship of these phases one to another is still somewhat obscure. Brues (1921) has implied that the polyphagous habit is derivable from, or is at any rate a later development than, the specific phase, and has in part come about owing to a parasitic insect usually possessing a shorter life-cycle and a consequently more numerous sequence of generations than a single host species, and thus requiring an alternation of hosts.

There is, however, some reason to believe that specific parasitism, just as the specific plant-feeding habit, is the outcome of an originally polyphagous habit, and has resulted from the adaptation of parasitic species to resist protection factors developed by host species. Indiscriminate host-selection seems to be even at the present day the commonest phase. Almost as common are cases of indiscriminate selection within the bounds of an insect order. Further, actual cases may be quoted where specific selection seems to be in process of evolution. Thompson (1913) describes the case of two closely allied weevils, *Hypera postica* and *Hypera punctata*. The former is infested by several parasites, amongst which nine are frequently and easily distinguished; three attack the eggs, and six (including a fungus) the larvae and pupae. *Hypera punctata*, on the other hand, is only parasitised by three species, even when in the same fields as *H. postica*: these three are a Mymarid egg parasite, a fungus, and an Ichneumonid parasite of the larva; the first two are parasitic upon *H. postica*, the last is a specific parasite of *H. punctata*.

It is possible that specific adaptation of parasite to host is bound up with the immunity of parasites to their host's internal juices. If a series of larvae of related parasitic species A, B, C, D, etc., forming possibly a genus or family, has become adapted to withstand the internal conditions of a series of hosts *a*, *b*, *c*, *d*, etc., a slight change in the chemical or the physical nature of the internal conditions of a particular host species may prevent some of the parasitic species from developing at its expense. In fact, only those parasitic species

whose larvae can quickly adapt themselves to the change will be able to utilise this host species successfully. Such adaptation of the successful parasitic species might throw them out of harmony with the remaining host species so that they become specific to a certain host species. Only in that species can they attain full development. It is not suggested that the adult female parasite will confine her oviposition to this host species—facts of superparasitism are against such a view; but whatever hosts her eggs are introduced into, only in the particular host species can the life-cycle of the resulting larva be completed.

In the *third* place, the parasite should be adaptable to fresh climatic conditions, and should possess the migratory habit, should possess greater powers of dispersal than the host.

*Fourthly*, it should be comparatively free from enemies and from the competition of other parasites. That is equivalent to saying that the host itself should be fairly free from enemies and from adverse conditions, because such enemies, whether predatory vertebrates or insects, do not discriminate between host and parasite, and adverse conditions react upon the parasite as well as the host insect.

The question of *hyperparasitism*—that is to say, the presence of secondary parasites upon the primary parasite of an injurious insect—is of very great importance from the point of view of parasite introduction. It is obvious that the value of a parasite may be entirely negatived if it be liable to severe parasitism itself—that is to say, if it possesses effective hyperparasites.

The question is complicated by the fact that the activities of the secondary parasite may be curtailed by the presence of tertiary parasites and these in turn restrained by quarternary parasites; further, cases are known where a parasitic species may be primary or may be secondary according to conditions. Take, for example, the case of *Dibrachys affinis*. As a primary parasite of the Vine Moth larva (*Polychrosis botrana*) it is beneficial. As a secondary parasite, however, of *Phytomyptera nitidiventris*, another primary parasite of *Polychrosis botrana*, it is inimical. It is also a secondary parasite of *Apanteles glomeratus*, the well-known parasite of the Cabbage White Butterfly *Pieris*, so that the proximity of cabbages to vines is undesirable; this is regrettable, since a valuable egg parasite of *Polychrosis*, namely *Trichogramma semblidis*, is also parasitic upon the eggs of the Cabbage Moth (*Mamestra brassicae*), and so would be encouraged by the proximity of cabbages.

A similar complication may be exemplified from Howard's account of the parasites of the Brown-tail Moth (*Euproctis*

*chrysorrhoea*). The Chalcidid *Monodontomerus aereus* is a *primary* parasite of the pupae of the Brown-tail Moth. It directly attacks cocoons of another primary parasite *Apanteles lacteicolor*, thus becoming a *secondary* hyperparasite. It thus competes with another secondary parasite *Mesochorus pallipes*, and comes into superparasitic relationship with it. It will also become *tertiary* if it chances to attack a cocoon containing *Mesochorus* as a secondary parasite of *Apanteles*. It is also parasitic upon Tachinid puparia, particularly upon *Zygobothria nidicola*, primarily parasitic upon the Brown-tail. *Monodontomerus* is also parasitised by *Pteromalus egregius*, which may thus be secondary or tertiary, according to the position of *Monodontomerus* at the time. *Pteromalus* may also act as a primary parasite of the Brown-tail Moth, and may possibly be a quaternary parasite upon *Mesochorus pallipes*. *Pteromalus* is parasitised by *Entedon albitarsis*, which may therefore be secondary, tertiary, quaternary, or even quinquenary.

It is doubtful whether any greater efficacy in action of introduced parasites is to be obtained by preventing the introduction of their hyperparasites. Secondary parasites seem to be less closely restricted to one or two species of hosts than are primary parasites; they are more polyphagous. Fiske (1910) regards this feature as representing a much more degraded form of parasitism, but possibly a more primitive form is indicated. Consequently the indigenous secondary parasites are quite ready to attack introduced primary parasites, whereas indigenous primary parasites, possessing more specific adaptation, are not so ready to attack introduced host insects. It is therefore more important that a parasite whose introduction is contemplated should be normally free from hyperparasites, rather than it should be artificially freed before introduction. Even then there is no guarantee that a parasite which is free from enemies in its own country will remain so when introduced into a different environment.

The condition which ensues if a host that normally affords only sufficient nutriment for one parasite individual be attacked by two or more species of primary parasites, or by one species more than once, is of extreme interest and importance from the economic standpoint.

Such **Superparasitism** (Fiske) or **Epiparasitism** (Haviland) or **Accidental Secondary Parasitism** (Dwight Pierce) is clearly distinct from the other form of double parasitism, **Hyperparasitism,** discussed above. In the latter case, one of the two parasites is attracted by the presence of the other parasite; in the former case both parasites are attracted primarily to the host.

As Fiske has pointed out (1910), in the case of two such superparasitic larvae in a host normally adapted for one, one of three things may occur. In the first place, one larva may conquer the other, either directly by devouring it or indirectly by bringing about the premature death of the host, and arrive to maturity, though often dwarfed or crippled. Secondly, both parasites may survive, in rare cases neither the worse for the circumstances, more frequently both so seriously weakened or stunted as to materially reduce their reproductive capacity. Thirdly, neither may survive, a condition induced either by the premature death of the host through excessive parasitism or by insufficiency of food.

Such superparasitism is a much more widespread occurrence than many entomologists will admit. In the case of Lepidopterous hosts, liable to be attacked by both Hymenoptera and Tachinid Diptera, the phenomenon is probably common, especially as many such Diptera do not directly attack the caterpillar but oviposit upon the surrounding foliage. Even among Hymenopterous parasites, which almost always attack the host directly, there is no evidence to indicate that a female parasite will refrain from attacking a host individual that has been previously attacked. In fact, the evidence is greatly in the opposite direction.

An illustration of the detrimental effect of superparasitism from the economic standpoint is afforded by certain investigations regarding the parasites of the Mediterranean Fruit-fly (*Ceratitis capitata*) in Hawaii. In 1913 two species of Opiine parasites were introduced by Silvestri. Of these, *Opius humilis* from South Africa is the more useful, parasitising sometimes 60-90 per cent of the Fruit Fly larvae developing in coffee berries. It suffers, however, from competition with the other Opiine, *Diachasma tryoni*, from Australia. When the larvae of both species occur together, in the majority of cases only that of *D. tryoni* survives, being more active, better protected ventrally, and having more powerful mandibles. Females of both these species, as well of a third Opiine, *Diachasma fullawayi*, readily oviposit in the same Fruit Fly larva, no discrimination between parasitised and unparasitised larvae being shown; as many as eight or ten Opiine larvae may occur in the one host individual, these parasitic larvae never completing their development.

In addition, there is unfavourable competition with a more recently introduced Chalcidid parasite, *Tetrastichus giffardianus*, which lays ten eggs to the Opiine one and so survives the Opiine by sheer force of numbers, should both types of larvae occur in the same host. Its influence upon

Fruit Fly control being imperceptible, its competition with the Opiines must be regarded as detrimental.

From the considerations which have now been reviewed it would seem that the ideal parasite from the point of view of artificial introduction into another area should be free from hyperparasites, should confine itself absolutely to one host species, which itself should be free from other parasites, predators, or adverse conditions generally. Even under these conditions superparasitism is always likely to occur, but is minimised if the host be larger in size than the parasites and so be able to nourish more than one individual.

Berlese (1916) adopts the following order of efficacy :

1. Exclusively specific parasites with few enemies and few adverse factors.
2. Polyphagous parasites.
3. Specific predators.
4. Polyphagous predators.

Against members of the Phytophthires (Scale insects, Aphides, etc.), which are usually exceedingly prolific, and whose minuteness of size accompanied by abundance of food enables them to withstand conditions adverse to larger insects, specific parasites or specific predators would seem to be the most important biological control factor, and introduction of such enemies in cases where an introduced Scale insect or Aphis has become a pest has been followed by striking success in numerous cases.

In Italy, for example, the Scale insect *Diaspis pentagona*, which at one time by its attacks upon the mulberry threatened ruin to silkworm industry, has been successfully controlled by the Chalcidid parasite *Prospaltella berlesei*, introduced by Berlese from America and Japan. *Prospaltella* fulfils the condition that requires superiority of fecundity. There are four to five generations per year, the females are parthenogenetic, lay about 100 eggs each, and apparently only one egg is laid beneath one individual host.

Further, it is easily acclimatised. A native originally of China, Japan, and before 1906 known only in the Far East, South Africa, and U.S.A., it has now been successfully established throughout Italy, Austria, Switzerland, Spain, and South America (Brazil, Uruguay, Argentine). It is almost free from hyperparasites. The few Chalcidid parasites it suffers from are separated in Italy, the centre of artificial distribution. It is said to suffer somewhat in South Africa from competition with a Coccinellid beetle (*Rhizobius*).

A similar successful example may be quoted from Hawaii,

where a little Fulgorid leafhopper (*Perkinsiella saccharicida*) of Australian origin, which was formerly the cause of extensive damage to sugar-canes, has been greatly reduced owing to the introduction by Perkins and Koebele of several species of egg-parasiting Hymenoptera.

The introduction of egg-stage enemies has been followed with success in many cases. The oft-quoted case of the specific predator, *Novius cardinalis*, is a case in point. This Coccinellid beetle was found by Koebele in 1888, in the North Adelaide district of Australia, reducing to comparative harmlessness the Fluted Scale (*Icerya purchasi*), which at the time was threatening extinction to the citrus-growing industry of California. The discovery was the outcome of a special search, based on the knowledge that in Australia this Scale insect occurred but was comparatively harmless. Large shipments of the beetle were sent to California, and the success of the experiment exceeded expectations. In fact, the Scale is no longer a factor to be reckoned with in citrus-growing, either in California or anywhere else where *Novius* can be introduced.

*Novius cardinalis* seems to afford a perfect remedy against the Fluted Scale. There are, however, many reasons in its favour that do not hold in the case of other beneficial insects.

In the first place, the host insect is fixed to the plant, and cannot escape the mobile beetle. Secondly, *Novius* is a rapid breeder, producing two generations to one of the Scale, and both larval and adult stages are egg-feeders. Thirdly, it is able to adapt itself to new environmental conditions: it has been introduced with success into Florida, Portugal, Egypt, Hawaii, Cape Colony, Syria, and Formosa. Finally, it seems to have no enemies. This latter feature is remarkable, since as a rule Coccinellid beetles are liable to attack by many species of Hymenoptera. Somewhat variable results, in fact, have followed attempts to introduce other species of Coccinellidae. Thus Koebele introduced also from Australia a Coccinellid, *Cryptolaemus montrouzieri*, into California to fight various Scale insects (*Pseudococcus, Lecanium, Pulvinaria, Eriococcus, Rhizococcus*), and claimed great success, but Silvestri was unable in Italy to obtain results of appreciable value. Many Coccinellid species belonging to the genera *Rhizobius, Lipernes, Serangium, Frithionyx, Scymnus, Chilocorus*, and, most promising of all, *Oreus chalibaenus*, have been introduced into California, particularly against the San José Scale (*Aspidiotus perniciosus*), but without marked success. No parasite, specific to this pest, is yet known, so that, although the attacks of the numerous polyphagous enemies that have been introduced may destroy sometimes as many as 90 per cent of the Scale

insects, the remainder are sufficiently numerous to cause serious damage.

A similar instance is afforded by the Scale insect *Saissetia oleae*, which may be destroyed in California to the extent of 70-80 per cent by the imported egg-devouring Chalcid, *Scutellista cyanea*; yet even this large percentage of mortality does not suffice to check excessive multiplication of the Scale insect when conditions afforded by the host-plant are favourable.

The activity of predators is still less marked against insects that are larger and more active than Phytophthires; but on the other hand the activity of parasites (internal predators) may bring about a constant, dependable percentage of mortality sufficient to restrict considerably the numbers of the insect host, although not sufficient to prevent periodical outbreaks brought about by excessive multiplication of the pest. Particularly is this the case with Lepidopterous host-insects. The Cabbage White Butterfly (*Pieris brassicae*) is an injurious pest, causing a serious amount of damage year after year, although so abundantly parasitised that excessive outbreaks are rare. The Gipsy Moth (*Porthetria dispar*) and the Brown-tail Moth (*Euproctis chrysorrhoea*), whilst regarded as injurious Bombycidae in Europe, cause really serious depredations only at intervals of many years. Since their introduction into the New England area of the United States, however, such outbreaks have been a constant annual feature, and enormous damage to forest trees has been the consequence. In the hope of minimising the ravages or of reducing them to the degree obtaining in Europe, large-scale experiments in the importation and introduction of European parasites have been initiated by Howard. Almost all the parasites of these two species from Europe and elsewhere have been introduced into the Massachusetts area, and it is hoped that as a consequence the depredations in this region will in time be definitely limited. The object aimed at has been the establishment of a sequence of egg, caterpillar, and pupal parasites, since it would seem very doubtful whether a Lepidopterous insect can be controlled by the agency of any one specific parasite (Howard and Fiske, 1912).

# CHAPTER V

## BIRD ENCOURAGEMENT

BIRDS may be divided, in accordance with their food-habits, into three groups :—

(i.) Birds that are *graminivorous*, relying almost exclusively upon a diet of seeds and fruits ; this group includes particularly the pigeons, parrots, and finches (sparrow, chaffinch, etc.).

(ii.) Birds that are *insectivorous* or *carnivorous*, a group including particularly aquatic and marine birds, falcons and hawks, owls, plovers, cuckoos, swifts, woodpeckers, and such families of Passerine birds as the flycatchers, swallows, Turdidae (thrush, blackbird, robin), and the Paridae (tits), although the two last-named families are to some extent graminivorous.

(iii.) Birds that are *omnivorous*, accepting seeds or insects with equal alacrity ; a group of birds that includes the Galliformes or Game-birds (pheasant, quail, grouse, partridge, fowl), the larks, the starlings, and the Corvidae (rook, crow, magpie, jay, etc.).

At first glance, birds in the first group would appear to be potentially injurious to the agriculturist if sufficiently numerous or if gregarious in habit ; birds in the second group would be potentially beneficial; and birds in the third group might be either injurious or beneficial, according to the nature of the crops grown in the locality, or the season of the year.

A superficial knowledge of the food habits of any bird or class of bird is, however, not sufficient to warrant any definite statement concerning the bird's economic position. An insect-eating bird, for example, cannot discriminate between the injurious and the beneficial insect, so that, of the six and a half million insects destroyed by a tit in one year, a large number has to be reckoned against the bird.

Collinge (1910), in his report on the food of the rook, reckons quite one-third of the animal food taken, against

the bird. Similarly, the activities of a carnivorous bird such as the sparrow-hawk may be positively detrimental to the interests of the agriculturist, since the majority of the small Passerine birds upon which it preys are the hedge-loving insectivorous forms, whereas such a hawk as the kestrel, preying chiefly upon moles and mice, can only be regarded as highly beneficial.

Even in the case of birds that are mainly graminivorous, conclusions based upon insufficient data may be erroneous. Investigations into the food of the chaffinch (*Fringilla coelebs*) by Theobald and by Leigh (1916), have yielded results quite at variance with the prevailing impression as to the destructive habits of this bird. The chaffinch is shown to take large quantities of such troublesome weed seeds as chickweed, hawkweed, dock, and knotgrass, the percentage of weed seeds in the crop contents being sometimes as high as 95. Grain was found in 41 per cent of the specimens examined, but appeared in most cases to have been taken from manure or from ricks in farmyards, and such seeds as clover and turnip were found in only 3 per cent of the birds. Judd (1898) asserts that in the United States no less than fifty species of birds act as weed-destroyers. Even such notorious grain-eaters as the English sparrow, bobolink, dove, and blackbird (*Agelaeus*, *Quiscalus*) will at times consume quantities of weed seeds, the first-named bird attacking particularly dandelion seeds. Meadow-larks and grosbeaks also render considerable service; goldfinches destroy weeds which are not touched by other birds, confining their attacks chiefly to one group of plants, the Compositae, a group which includes many troublesome weeds. The most efficient weed-consumers, however, appear to be the score or more of native species of sparrow that flock to the weed patches in early autumn and remain until late spring.

The economic position of such weed-consuming birds, however, would depend upon whether weed seeds can pass through the alimentary canal of the bird intact and capable of germination. Judd (1900), as a result of extensive experiments with English sparrows, concluded that even with such seeds as are swallowed whole, very few pass through the bird in a condition to germinate.

The results obtained by Kerner (1895) from a very extensive series of experiments are, however, more conclusive. Fruits and seeds of some two hundred and fifty different species of plants were fed to the following birds: duck, turkey, fowl, pigeon, crossbill, bullfinch, titmouse, serin-finch, goldfinch, nutcracker, siskin, raven, jackdaw, robin, rock-thrush, song-

thrush, and blackbird. The faeces were examined after each meal to ascertain what seeds they contained, and were then placed on the surface of plots of earth.

In such birds as the turkey, fowl, pigeon, duck, crossbill, siskin, nutcracker, titmouse, serin-finch, which grind up even the hardest seeds and fruits in their muscular gizzards, and which frequently strip the fruits and seeds before swallowing them, no seed from the faeces was found capable of germinating.

In the case of ravens and jackdaws, the stones of the drupes and hard-coated seeds of berries passed uninjured through the alimentary canal, but soft-coated seeds and fruits were all destroyed. Cherry stones, for example, were able to germinate.

In the case of the blackbird, song-thrush, rock-thrush, and robin, however, seeds were rapidly excreted, and a high percentage was able to germinate; thus 75 per cent germinated in the case of the blackbird, 85 per cent in the case of the thrush, 88 per cent in the case of the rock-thrush, and 80 per cent in the case of the robin.

Collinge (1913) carefully collected a large supply of bird droppings from a garden fence and placed them in sterilised soil; the following plants were obtained: sycamore (*Acer pseudo-platanus*), ribwort-plantain (*Plantago lanceolata*, Linn.), mouse-ear chickweed (*Cerastium vulgatum*, Linn.), broad-leaved dock (*Rumex obtusifolius*, Linn.), groundsel (*Senecio vulgaris*, Linn.), and charlock (*Sinapis arvensis*, Linn.).

It would seem doubtful, therefore, whether the habit of consuming weed seeds is sufficient to confer upon a graminivorous bird a beneficial status. They may keep weeds down to a certain extent, but it is very probable that such diminution in the weeds of a particular area is counterbalanced by a wide distribution of such weeds elsewhere.

Another factor that must be taken into consideration, in estimating the economic status of a species of bird, is the nature of the food taken by the nestlings, for not only is the quantity of food per day consumed by a nestling relatively enormous, but almost all birds except doves and pigeons feed their young upon an animal diet, irrespective of the diet of the adult. As nestlings increase in weight from one-fifth to one-half daily, and at certain stages of growth require daily more than their weight of food, it is essential that the food should have a high nutritive value and should be easy of digestion. Spiders, caterpillars, and grasshoppers are therefore a favourite nestling food with many species of Passerine birds. Birds such as finches, that are largely vegetarian, mingle fruit or grain in constantly increasing quantities with the insects fed to their young,

though insects predominate in the diet until maturity is nearly reached. These birds, however, generally make use of hard insects—carabid beetles, weevils, and so on; but sparrow nestlings will consume a comparatively large number of caterpillars. An interesting example of this is afforded by Tegetmeier's investigation into the dietary of the English sparrow, as quoted by Günther (1916).

| Diet. | Of Adult. | Of Nestling. |
|---|---|---|
| Corn . . . . . . | 75 per cent | 40 per cent |
| Weed seeds . . . | 10 ,, | Nil |
| Green peas . . . | 4 ,, | Nil |
| Beetles . . . . . | 3 ,, | 10 per cent |
| Caterpillars . . . | 2 ,, | 40 per cent |
| Other insects . . . | 1 ,, | Nil |
| Miscellaneous . . . | 5 ,, | 10 per cent |

On the whole, therefore, sweeping statements concerning the utility or the uselessness of any particular species of bird are to be deprecated; its economic position will depend to a large extent upon the abundance of the bird, upon the availability of food other than its preferred food, upon the nature and times of crops in the locality. Particularly is this the case with regard to birds whose diet is a mixed one. Evidence from isolated observations, from crop examination of only a few examples, shot perhaps in restricted localities, or at some definite time of the year, is worse than useless. The data required must be based upon crop-examination of *large numbers* of specimens, from *widely distributed* localities, throughout *all* months of the year for several years. The exact locality of each specimen should be known, the character of the land, the crops grown there, whether the district is wooded, whether broken up by hedges or ditches or walls, what the bird was doing when shot, whether it was in a flock, what the weather was like, and so on. Such evidence must be supplemented by similar crop examinations of nestlings, and by numerous, well-authenticated field observations. In the past, the method of estimating the crop contents has been a numerical one, but it is probable, as Collinge (1918) has pointed out, that such a method is misleading and inaccurate, and that the volumetric method, estimation of percentage by bulk, is more reliable and should be substituted for the numerical method.

Investigations on such lines have been carried out in Great Britain by Collinge, Newstead, Theobald, Leigh,

Hammond, Tegetmeier: in the United States by Judd, Beal, and others: in India by Mason and Lefroy; but considerations of space will not permit of any detailed account of the mass of facts thus available regarding the dietary of many common birds.

It may be affirmed, as regards Great Britain, that most authorities are agreed that the house sparrow, tree sparrow, and wood-pigeon are inimical to cereal production. The crop of a single wood-pigeon, to quote an example furnished by Milburn (1918), was found to contain:

| | |
|---|---|
| Barley grains | 561 |
| Clover leaves | 113 |
| Rye-grass seeds | 986 |
| Clover seeds | 108 |
| Weed flowers | 60-80 |
| Insects | Nil |

The rook, bullfinch, lark, blackbird, and missel-thrush are injurious if in excessive numbers; the pheasant is injurious if carelessly managed; the starling, chaffinch, and seagull beneficial on the whole; and cuckoos, swifts, lapwings, woodpeckers, and the majority of Passerine birds, particularly Paridae (tits), Turdidae (thrushes), Muscicapidae (flycatchers), and Hirundinidae (swallows), are of the utmost value.

In the United States, according to Pellett (1914), the following birds should be protected: the blue jay, one of the very few birds fond of hairy caterpillars such as Tent-caterpillars (*Malacosoma* sp.); the crow, which controls June Beetles (*Lachnosterna*), white grubs, and young field-mice; the sparrow-hawk (*Falco sparverius*), which feeds chiefly on grasshoppers and crickets; robins, thrushes, and catbirds, the last of which feeds its young on cabbage worms; the cuckoo, which also eats hairy caterpillars; woodpeckers, which destroy ants, borers, and insect eggs in winter; the flicker, which eats ants in large numbers; orioles, which are particularly fond of Aphides; and quails, which are in special need of protection owing to their destruction for food, and which devour the Colorado Potato Beetle (*Doryphora decemlineata*), the Striped Squash Beetle (*Diabrotica vittata*), the Boll Weevil (*Anthonomus grandis*), the Chinch Bug (*Blissus leucopterus*), grasshoppers, cutworms, and many other injurious insects.

A little space may be devoted, however, to the question of the rook, starling, pheasant, and little owl in Great Britain, and the question of the American crow and the horned lark in the United States.

The economic position of the rook has long been a matter of controversy; whilst, speaking generally, farmers condemn

the rook, ornithologists are inclined to champion the bird as being of benefit to the agriculturist. Some light has been shed upon the question by the work of Collinge (1910, 1920). In his report upon the crop contents of 830 rooks shot during the period 1908-1909 throughout England and Wales, he asserts :

(i.) That 67·5 per cent of the food of the rook consists of grain ; if roots and fruits be added, the percentage is 71.
(ii.) That the animal food content was only 29 per cent, and of this quite one-third must be reckoned against the bird.
(iii.) It seems clear that the birds examined preferred grain to any other kind of food: probably it is more plentiful and easier to obtain than insects.
(iv.) Careful calculations show that each rook consumes about 16 oz. of food per week, or 52 lbs. per year. Accepting this figure as being probably reasonably accurate, it may be reckoned that ten thousand rooks will consume about 232 tons of food in a year, comprising about

80 tons of cereals.
32 tons of potatoes and roots.
7½ tons of beneficial insects.
65 tons of injurious insects, slugs, snails, etc.

That is to say, the rook would not appear to be a particularly beneficial bird to the agriculturist, although its usefulness might be considerably increased were it fewer in numbers.

These conclusions are supported by the work of Theobald and Leigh, working for the Economic Ornithological Committee appointed by the British Association of Science in 1908. Leigh (1916) states that the percentage of grain is very high during the period September to the following May, but falls to a low level during June, July, and August. In these months the bird is undoubtedly of great benefit to the farmer, the percentage of animal food being high and composed of injurious insect larvae such as leather jackets (*Tipula* sp.) and wireworms. The evidence, however, regarding the dietary of the rook is still insufficient to determine the bird's economic position. More field observations are urgently needed. Rooks in September and October, for example, may obtain their grain by gleaning during harvesting operations. Evidence regarding the food of nestling rooks is also very scanty.

Methods advocated for thinning out rooks, such as spring and summer shooting, do not always take into consideration the fact that the summer rooks are often distinct from the winter rooks. On the East Coast of Great Britain particularly there is a considerable inter-migration between our

shores and the European continent. The summer birds reach England in March, breed here, and leave for the continent in September and October. The winter rooks breed in Central Europe and Scandinavia, reach England during October and early November, and commence to leave for Central Europe in February and March, for Scandinavia somewhat later. The summer birds are generally scattered in small rookeries, and are probably beneficial on the whole. The winter rooks, however, aggregate in great flocks, occupy large rookeries, and are undoubtedly the principal culprits. Shooting of rooks in late autumn or winter is therefore preferable to shooting in spring.

### The American Crow

The case of the American crow (*Corvus americanus*) is analogous to that of the rook. It is a bird generally condemned as a destroyer of eggs and young of domestic and wild birds, and a devourer of grain. Examination of a large number of crops, however, has shown that these charges, except the one regarding the eating of grain, are somewhat exaggerated. The percentage of insect food is considerable; Lamellicorn beetles would seem, in fact, to constitute the principal food during spring and early summer. Large quantities of grasshoppers are taken in August. Grain, however, is extensively taken during autumn and early spring from newly planted fields, the grain being preferred when it has been softened by germination.

### The Starling

Reliable evidence concerning the food of the starling (*Sturnus vulgaris*) in Great Britain is available in the reports of Leigh and Theobald, mentioned above, and from the work of Hammond (1912). These inquiries have shown that the percentage of animal food taken by the starling is very large, and made up chiefly of injurious insects. A fair proportion of grain has been recorded, but not by any means so large as in the case of the rook. Grain occurred particularly in birds shot during November and December; even then, the percentage of grain was less than that of injurious insects. It is during these months that the large flocks of Scandinavian immigrants arrive.

On the whole, therefore, during ten months of the year the starling is a very useful bird. During the remaining two months his excessive numbers and the scarcity of insect food force him to seek insects at the roots of cereals and to root up and possibly devour part of the young plants themselves.

The food of the starling in the United States has been very closely investigated by Kalmbach and Gabrielson (1921), who, as the result of the examination of a large series of crops, and extensive field observations in those parts of the United States where the bird is most abundant, assert that this bird is equalled by few birds in the north-eastern area of the United States as an effective destroyer of insects, which comprise 41·55 per cent of its food.

Of this quantity of insect food, nearly half consists of Coleoptera, particularly weevils (8·5 per cent), Carabids (5·7 per cent), and Lamellicorns (2·2 per cent). Of the Carabids, the greater number eaten are vegetarian, notably species of *Harpalus* and *Anisodactylus*. The Lamellicorns consist largely of eleven species of *Lachnosterna*, the May Beetle adult of the notorious "white grub." Orthoptera constitute 12·4 per cent of the starling's food, especially in October and November, Tettigoniids and Gryllids predominating.

Lepidoptera, mainly caterpillars, are chiefly attractive to nestlings, forming 38·2 per cent of the food of very young starlings. The caterpillars were chiefly cutworms. In the adult crops, Lepidoptera constituted 6 per cent of the yearly food.

### The Pheasant (*Phasianus* sp.)

In spite of the way that pheasant-rearing has been mixed up with political controversy in Great Britain, the recorded evidence concerning the economic aspect of the bird is not overwhelming. Günther (1916) has accumulated a considerable number of facts bearing upon the question, and these, together with an examination of crop contents carried out by Miss Evershead at Cambridge, England, and one carried out by Berry (1917), would seem to indicate that, apart from hand-fed grain, the pheasant relies from October to March upon weed seeds, spangle galls from oak leaves, and acorns; in spring, a certain amount of clover was found; during summer the diet seems to be chiefly insects, weed seeds, and cereal grains. According to Berry (1917), exhaustive analyses of the crop contents of 183 pheasants obtained from all parts of the country and at various times of the year have disclosed the remains of over 100,000 injurious beetles and other insects, a varied assortment of vegetable refuse, 421 wild berries, weed seeds, etc., and only 37 husks and fragments of grain. The examination of the crop of one young cock pheasant from Argyllshire yielded—Diptera: *Bibio lepidus*, 2286 specimens; Coleoptera: *Lochmaea suturalis*, the heather beetle, 508 specimens; ants and grasshoppers, 6.

"The main point to be noticed about the pheasant's dietary is that it is a varied one; the bird is not dependent upon any single foodstuff; he likes a change, and this it is that has brought him into the farmer's black books. When pheasants have got to the end of the foods that the woods afford, they stray on to arable land, beginning no doubt with easily seen insects, and then if not scared off in time will satisfy their hunger on the crops. Their chief vanities are peas and beans, and they are so fond of these that they will dig deeply, even three inches down for them" (Günther).

### The Horned Lark

The horned lark is a small but hardy bird which frequents the open country and never lives in forests. It occurs in all parts of North America except the Aleutian Islands, the southern coastal portion of Alaska, the extreme south-eastern United States and Central America. It occurs also in Europe. There is only the one species, *Otocorys alpestris*, but there are a large number of sub-species. The economic status of the bird is a matter of dispute.

McAtee (1905), as a result of the crop examination of more than a thousand specimens, asserts that the great bulk of the food consists of weed seeds, the actual percentages found by him being: insects, 20·6 per cent; vegetable matter, 79·4 per cent, six-sevenths of which consist of weed seeds.

The horned larks of California, however, differ markedly in food habits from those in other parts of the country, being almost entirely vegetarian, and although the number examined constitutes little more than a fifth of the total, yet they consume four-fifths of all the grain eaten by the whole group as shown by the following table:

| Grain. | California. | Elsewhere. |
|---|---|---|
| Oats . . . . . . | 31·1 per cent | 4·86 per cent |
| Wheat . . . . . | 9·1 ,, | 1·66 ,, |
| Corn . . . . . . | Trace | 4·97 ,, |
| Buckwheat . . . | None | ·68 ,, |
| Total . . . | 40·2 per cent | 12·2 per cent |

In spite of the above facts, however, it would be incorrect to assume that the horned larks in California are injurious to grain production. The buckwheat is negligible; practically all the wheat and oats eaten is waste. Although the Great

Plains region, the most important wheat-growing area of the country and a centre of abundance of the bird, is represented by a proportionate number of crops examined, yet the percentage of wheat eaten is only 1·66; in fact the larks of this region, considered separately, are even more insectivorous than those from east of the Mississippi, one-fourth of their food being animal matter.

Although the belief of farmers that this bird eats newly-sown wheat appears to be supported by the facts of the inquiry, McAtee considers that the insects eaten by the bird compensate manifoldly for the seed grain taken, and that on the whole the horned lark is to be regarded as highly beneficial to the agriculturist.

### The Little Owl, *Carine noctua* (Scop.)

was introduced into Great Britain and liberated from various centres, particularly in Kent and Northamptonshire, some thirty or forty years ago, and has proved to be a most successful colonist, being now fairly abundant in most parts of the country. There is, however, considerable prejudice against the bird, particularly on the part of poultry farmers and gamekeepers, and advocates of repressive measures are not lacking.

From the observations of several authorities, Coward (1912), Meade-Waldo (1912), Collinge (1922), and others, however, it appears that the pellets of indigestible food thrown up by old birds contain remains of voles, mice, rats, shrews, beetles, insects, and sometimes birds and frogs. The nests or hoards of food stored up may contain in addition remains of Passerine birds such as thrush, missel-thrush, blackbird, tits, sparrows, chaffinch, bunting, skylark, and greenfinch. Meade-Waldo asserts that in fifteen years he has never found a game-bird in a nest or hoard, but two other observers record cases of young pheasants being found. Earthworms are noted as not infrequently taken. Collinge (1922) claims that the bird is second to the lapwing in the destruction it inflicts upon wireworms and clickbeetles. It appears, in fact, that damage to game occurs but rarely and that, on the whole, the Little Owl can be regarded as a distinctly useful addition to the fauna of England.

### Bird Discouragement

It is obvious that whatever the food habits of a bird may be, that bird will not take rank as an economic nuisance unless

it occurs in great numbers and is widely distributed over an area where the nature of the crops grown is uniform. Isolated effort, therefore, whether scaring, shooting, trapping, or poisoning, directed against such a species will be almost useless. Only collective and well-organised methods can bring about results commensurate with the labour and expense involved.

In the case of the immigrant woodpigeons, which aggregate in enormous flocks within a restricted roosting place such as a fir wood, organised evening shoots, if sufficient guns are available, have given good results, and the market value of the birds obtained will generally repay cartridge expenditure, but organised shooting of small birds such as flocks of sparrows is of course out of the question.

In this connection, the value of properly conducted sparrow clubs cannot be overestimated. Günther (1916) quotes, as an example of a successful sparrow club, the Framingham and District Sparrow Club (Norfolk). In 1915, the acreage and other subscriptions came to £16. Old birds were paid for at the rate of fourpence per dozen; fledglings and eggs at the rate of twopence per dozen. The following results were obtained:

| | 1914. | 1915. |
|---|---|---|
| Old birds killed . . . | 6300 | 6486 |
| Fledglings and eggs . . . | 6834 | 3387 |

The great objection to organisations of this kind is of course the fact that they are based primarily upon the predatory instincts of children, and unless very carefully controlled, unconsciously encourage the indiscriminate slaughter of all small birds, injurious and beneficial, and so in the long run may do more harm than good. Günther recommends the use of strychnine against sparrows. A pint of wheat dressed with strychnine will destroy hundreds of sparrows at a very low cost.

Scaring methods, though admirable from a humanitarian standpoint, are economically unsound. Even if an efficient mechanical scarer could be discovered and could be used on a large scale, the effect would be merely palliative. The bird flocks are obliged to feed somewhere, and will either be driven to areas where scares are not used or, emboldened by desperation, will become tolerant of them.

## Bird Encouragement

In a cultivated area the balance of nature is to a large extent disturbed. Woodlands become destroyed, hedges give place to fences: marsh and moorland become replaced by

arable land or drained pasture. The diminishing number of birds that manage to tolerate the restricted breeding conditions becomes steadily reduced by indiscriminate application of the discouragement methods alluded to above, and by the attentions of that trio of self-styled bird lovers, the gamekeeper, the bird-catcher, and the ornithologist.

A rational system of bird encouragement, therefore, should not be merely passive; it should not confine itself to the enactment of legislative protection measures that are too often allowed to become a dead letter, but should include *active* measures that will tend toward an increase quantitatively and qualitatively in bird life. This can only be done by the creation of Bird Sanctuaries, definite reservations for bird life, ranging in size from tracts of country down to artificial coppices in the public parks of urban districts. Within the bounds of such reservations, the Bird Protection Laws must be rigidly enforced; outside the bounds, the laws could be relaxed sufficiently to avoid hampering the agriculturist.

It is satisfactory to note that such bird reservations are increasing in number. Great Britain possesses the Brent Valley Sanctuary; Canada has created one at Rockcliffe Park, Ottawa; Germany possesses numerous such reservations, notably the large one at Eisenbach, Thuringia, established by Baron von Berlepsch; the United States possesses a large reservation on the confines of Oregon and California, one in Florida, and one at Marsh Island, near New Orleans.

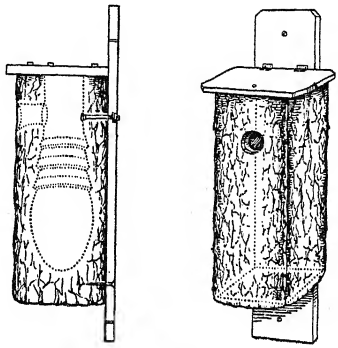
In such sanctuaries, conditions should approximate as closely as possible to those of the primeval woodland and swamp. Clean forestry is incompatible with bird profusion. Decayed and fallen trees, plenitude of brushwood, standing pools and meres, should not merely be tolerated but should be supplemented by the provision of nesting boxes and by the planting of thorny shrubs to form dense impenetrable thickets and undergrowth, thus affording nesting facilities to different types of birds.

### Nesting Boxes

Many types of nesting box can be obtained. The type designed by Baron Berlepsch (Fig. 4) and procurable in Great Britain from the Royal Society for the Protection of Birds, 23 Queen Anne's Gate, London, is based upon the preference shown by many small birds for the deserted holes made by woodpeckers, and is, in fact, an exact reproduction of such a hole. It consists of a solid section of alder, birch, or pine in which has been bored a bottle-shaped cavity with

a pointed oval base and a lateral aperture that slopes slightly upwards. The section is about twelve to twenty inches long, by six or eight inches in diameter, is fastened to an oak batten by screw bolts and is provided with a slightly overhanging lid. The cavity has a maximum diameter of four to seven inches, and the exit aperture has a diameter of one half to three and a half inches.

Berlepsch has laid great stress upon the pointed oval base of the cavity and the characteristic slope of the opening at an angle of four degrees. Whilst not disputing the superiority of the Berlepsch box over any other type, particularly for such birds as the wryneck, woodpecker, or stockdove, which use little or no nesting material and are unwilling to use boxes in which the pointed oval trough is lacking, the experience of the authors has been that a considerable degree of success is obtainable even with roughly fashioned flat-bottomed bird boxes. In large scale experiments in bird encouragement conducted by the University of Manchester in the saw-fly-infested larch plantations around Thirlmere Lake, Cumberland, between 1908 and 1914, the Berlepsch box was abandoned in favour of a box constructed from flat slabs of refuse larch with the bark on, that could be knocked together very cheaply on the spot. Four hundred such boxes gave an occupancy-percentage of 81, the occupiers being tits, robins, and starlings, with a few pied fly-catchers.



Berlepsch. Thirlmere.

FIG. 4.—Types of nesting box.

There is a right and a wrong way of hanging bird boxes (Fig. 5). The late autumn is the most favourable time of the year. The height of the box above the ground should be at least ten feet, and may be considerably higher. As a rule only one box should be placed on a tree, and a fifteen yard radius between boxes should be allowed.

Boxes should be hung more thickly on the edges of woods and where the growth is less dense. The box should slope slightly *towards* the direction faced by the opening, not away from it, and the opening should not face the weather side.

Birds such as robins, redstarts, pied wagtails, etc., that prefer a semi-open cavity can be catered for by shallow half-open bird boxes or by artificial niches in walls. The large

number of birds that eschew holes and nest in thickets will necessitate artificial planting of thorny shrubs such as hawthorn, gooseberry, dogrose, etc., or such trees as beech, hornbeam, elder, mountain ash, in fact any young tree or bush that will bear pruning and will grow thick in consequence is suitable. Details regarding the creation of artificial shelter woods may be found in Hiesemann's book (1912).

Shelter coppices in urban districts must be proof against

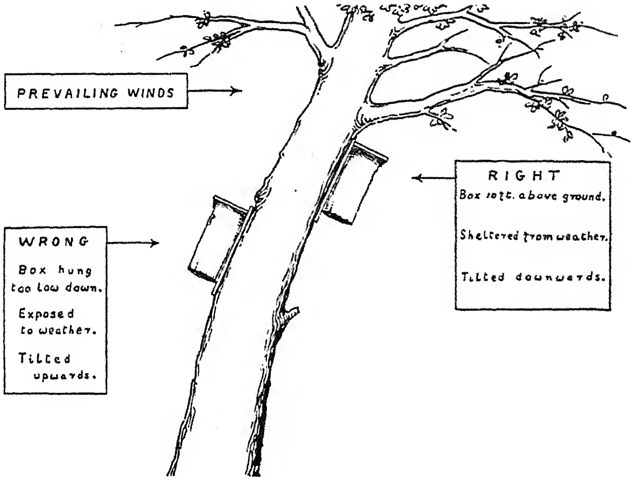



FIG. 5.—Method of hanging bird boxes.

the ubiquitous cat. A thick hedge of hawthorn or holly, supplemented by a fence of wire-netting six feet high and curved at the top like an inverted J, serves very well.

A certain amount of winter feeding will be required, particularly during intense frosts. Elaborate directions will be found in the above-mentioned work by Hiesemann. At Thirlmere, the Hessian Food House was made use of; this consists of a roof resting on four corner posts, and a central post bearing two flat food trays upon which a mixture of seeds and suet was placed periodically.

# PART II

## CHEMICAL CONTROL

## CHAPTER VI

### INSECTICIDES

THE recognition and employment of chemicals in the control of insect pests have been from the first concomitants of accidental discovery and empirical application rather than the outcome of a train of scientific observations and logical deductions therefrom, and the introduction of fresh insecticidal substances has coincided nearly always with some sporadic outbreak of insect injury.

We find also an early tendency to draw upon the facts of human toxicology and to distrust the application of substances whose toxic action upon higher animals appeared doubtful or non-existent.

Compounds of arsenic, of copper, and of lead were therefore among the first substances to be tried. Not only was their known toxicity high, but being in extensive use as painters' colours they were comparatively cheap in price and easily procurable in a condition ready for application. Thus an acetoarsenite of copper, known as *Paris Green,* in popular use as a shutter paint, was introduced between 1860 and 1870 in America against the Colorado Potato Beetle, and had a tremendous vogue against all and sundry insect pests until superseded by lead arsenate.

Again, the valuable fungicide known as *Bordeaux Mixture* was the outcome of a chance observation by Millardet in 1887 that grapes which had been sprinkled with a mixture of lime and crude copper sulphate in order to deter pilferers withstood the prevalent epidemic of Downy Mildew better than grapes which, not growing by the roadside, had not been so treated.

On the other hand, substances whose poisonous effect upon higher animals is slight or doubtful, as, for example, the various sulphides and polysulphides, have come into use comparatively recently, although comprising insecticides of great value.

The restriction in choice of insecticides to substances whose toxic properties were more or less obvious, and the unfortunate tendency towards imitation of results rather than improvement upon them, have brought about a striking paucity in the variety of substances that are employed. The insecticide manufacturer and the agriculturist have preferred to imitate and repeat the results of some chance discovery rather than to investigate the insecticidal value of fresh substances, and, as Lefroy (1915) has pointed out, waves of fashion in insecticide popularity have followed one another.

The vogue of Paris Green and London Purple gave way to that of lead arsenate, and this substance, as a result of high prices and scarcity during the Great War, is becoming superseded by the arsenical salts of barium and zinc and by vegetable poisons. Paraffin emulsions and resin washes were succeeded in popularity by whale oil soap; this in turn by lime, salt, and sulphur preparations, by heavy oils and by miscible oils.

These substances have been applied often without due regard to their exact mode of action, to the optimum meteorological conditions, or to the particular requirements of the pest and the host plant under consideration.

However, within recent years, it has become recognised that such empirical groping after a desired combination of high toxicity, cheapness, and ease of manipulation may lead to the neglect of certain other factors equally essential to the production of the perfect insecticide, factors which can be profitably investigated only by well-organised research upon systematic lines, and owing to the efforts particularly of Cooper, Lees, Lefroy, Nuttall, Pickering, Theobald in Great Britain, of Graham, Lovett, M'Clintock, Moore, Shafer, Tartar, Woglum in America, and of Bourcart, Dantony, Vermorel in France, our knowledge of insecticides is gradually becoming placed upon a more scientific basis; the old view that considered cost, killing power, and ease of manipulation as the chief qualities required in an insecticide is, in fact, giving way to the view that such factors as spreading power, wetting and penetrating power, and toxic action as distinguished from mere toxic effect are equally important adjuncts to the commercial qualities mentioned above.

The essentials of an insecticide may be summarised therefore as: (1) *high toxic effect in proportion to cost and to permissible strength*; (2) *ease of miscibility*; (3) *high adhesivity*; (4) *complete insolubility in the fluid used as a base*; (5) *spreading power*; and (6) *wetting power*.

Qualification (4) applies more especially to stomach poisons, qualifications (5) and (6) to contact insecticides.

### Toxic Action

The toxic action of an insecticide will vary according to whether the poison is introduced by way of the alimentary canal (*stomach poisons*) or by way of the respiratory tract or through the cuticle (*contact poisons* and *fumigants*).

It has been generally considered that a substance having a high toxic effect upon a higher animal will act equally well as an insect poison, and in the past, stomach poisons have almost always consisted of inorganic metallic compounds, particularly combinations of copper, lead, and calcium with arsenic acid, although the difficulty of assuring that such compounds do not injure the host, whether plant or animal, has always suggested the desirability of some other class of substance equally poisonous to the insect but less so to the host. It is by no means certain that the toxic action of chemical substances upon insect metabolism is similar to the results observed in mammalian toxicological experiments. Forel (1908), for example, states that hundreds of the ant *Myrmica scarbrinodis* crammed themselves full of honey containing arsenic acid without a single one of them appearing to suffer. Strychnine introduced in strong doses into small wounds produced no cramp and the ants only died therefrom very slowly.

Cooper and Nuttall (1915) suggest the possibility of using organo-metallic compounds, these being considerably less toxic than organic compounds towards the higher animals and plants, but equally poisonous to insects. Organic arsenical compounds would appear to be usually too expensive, and the use of copper compounds is suggested, as, for example, *cupric-dimethanol-disulphite* ($Cu(H_2C . OH . SO_3)_2$), prepared in solution by passing sulphur dioxide into a suspension of copper hydroxide in formalin (40 per cent formaldehyde). The solution contains 3 per cent of copper and combines the insecticidal effects of copper and sulphur.

Investigations at the Woburn Experimental Fruit Farm, by Pickering, regarding the relative effects of various stomach poisons, indicate that, of the vegetable poisons tried, tobacco yielded the best results on the whole, results generally better than obtained with lead or calcium arsenate or Paris Green, but even better results accrued from the use of a $1\frac{1}{2}$ per cent emulsion of solar distillate oil made with iron sulphate : 8 oz. of iron sulphate are precipitated by 4 oz. of lime, or $9\frac{1}{2}$ gallons of limewater ; 24 oz. of solar distillate are churned into it and the resulting emulsion made up with water to 10 gallons. The absence of unprecipitated iron should be ensured by testing with potassium ferricyanide (Pickering, 1906-1910).

The crying need for some standard of comparison by which the toxic value of an insecticide could be readily estimated has long been evident. Holloway (1912) has suggested that the length of life of a poisoned insect be taken to indicate the toxic value of the chemical to which that insect is subjected; the toxic value of two chemicals would thus vary inversely with the lengths of life of two insects respectively subjected to them, assuming that the insects are of the same species, and at the same period of their life-cycle, and that environmental conditions are equal. He suggests that Paris Green Lavanburg be taken as the standard, and that the *Poison Exponent* for any poison be arrived at by comparing the length of life of an insect larva subjected to that poison with the length of life of a larva subjected to Paris Green Lavanburg at the same time. That is to say,

if $x$ = unknown poison
1 = Paris Green or standard in toxic value.

Then if an insect subjected to $x$ dies after ten hours, and an insect subjected to Paris Green dies after five hours,

*then toxic value of* $x$ : *toxic value of Paris Green* : : 5 : 10,
*i.e.* 10 *T.V. of* $x$ = 5 *T.V. of Paris Green*,
*therefore* 5 *T.V. of* $x$ = 5/10 *T.V. of Paris Green*
= ·50, which may be called the *poison exponent* of $x$.

Much light has been shed upon the toxic action of contact and gaseous insecticides by the work of Moore and of Shafer, and the effects produced by this class of insecticides would seem to be brought about in two ways:

1. These substances may block up the spiracles and so bring about death by suffocation. Moore has shown that fat solvents, oils, and soaps are able to penetrate the tracheae of insects by capillarity; that death can be caused by practically non-volatile and non-toxic oils; and that these substances prevent normal oxidation taking place in the body of the insect and bring about suffocation.

   Such a mechanical insecticide is capable of giving good results when applied to small insects such as Aphides, but cannot be relied upon against larger insects or against insects, such as *Pediculus*, which are able to close their spiracles very quickly, as the possibility of all the tracheae becoming plugged is unlikely. It is preferable, therefore, to add to the spray a solution that can kill in a chemical manner, so that the insect will succumb even

if only one trachea be filled. Solutions of soaps which have a large proportion of free alkali are thus more toxic than those which are practically neutral.

2. The second way in which the contact insecticide may kill is by penetration of the external chitin or the chitinous lining of the tracheae, and acting upon the internal tissues. Certain non-volatile substances such as alkalies, corrosive sublimate, possibly borax and sodium fluoride, though not capable of penetrating into the tracheae if in aqueous solution, may, according to Shafer (1915), slowly penetrate the external chitin and dissolve or precipitate certain constituents of insect tissues.

The rate of penetration appears to be inversely proportional to the surface tension of the fluid and to the thickness of the chitin, so that in the case of a fluid whose surface tension enables it to pass into the tracheae the rate of penetration through the thin tracheal lining is comparatively rapid.

Although relatively non-volatile oils, if of low viscosity, can thus enter the tissues of the insect through the tracheal walls, better results are found to occur with substances of slight volatility, as the vapour penetrates chitin far more quickly than the fluid does. Nicotine in aqueous solution, for example, cannot enter the tracheae in liquid form but may penetrate the spiracles and pass through the tracheal walls as vapour.

Generally speaking, substances with low volatility are more toxic than substances whose volatility is high. Moore (1917) suggests that the vapour, on reaching the finer branches of the tracheal system, tends to condense on the tracheal walls. If the substance is very volatile, it will tend to evaporate and pass out of the insect again, but if of low volatility it will remain, penetrate into the tissues, and produce poisonous reactions. The high toxic action of such highly volatile compounds as *carbon bisulphide, chlorpicrin,* and *ethyl mercaptan* may be due to an abnormal power of penetration, and the high toxicity coupled with high volatility of *hydrocyanic acid gas* is undoubtedly correlated with its high solubility in water, but apart from these and a few other exceptions Moore regards such physical characters as Boiling Point and Vapour Pressure as having more influence upon toxicity than chemical constitution. Up to a limit of 250 degrees C. the toxicity is directly proportional to the boiling point ; beyond this temperature, however, a substance usually volatilises so slightly that unless an insect be exposed to its influence for a long period of time its toxic effect is almost negligible.

According to Tattersfield and Roberts (1920), however, while such physical properties as volatility, vapour pressure, rate of evaporation, undoubtedly control the toxic action of particular compounds, the toxicity of the chemical group to which the compound belongs is dependent upon chemical constitution. Thus, for example, the aromatic hydrocarbons and their halogen derivatives are, as a group, more toxic than are the aliphatic hydrocarbons and their halogen derivatives, although it is possible that owing to physical properties particular aromatic hydrocarbons may show less toxicity than that shown by certain members of the aliphatic group. That chemical constitution does largely influence toxicity is indicated, too, by the fact that if certain chemical radicles be added to, or substituted in, the ring or chain structure of a substance, the resulting product may be considerably more poisonous than the parent substance, and by the fact that isomeric substances are not necessarily equally toxic.

Thus the radicles which influence toxicity most when introduced singly into the benzene ring are, in order of importance: the methylamino ($NHCH_3$), dimethylamino $N(CH_3)_2$, hydroxyl OH, nitro $NO_2$, amino $NH_2$, iodine, bromine, chlorine (in nucleus), methyl $CH_3$.

The presence in the ring of other substituents, however, greatly modifies this order. If, for example, a methyl radicle has been already introduced, that is to say if the parent substance be *toluene*, the order becomes : chlorine (side-chain), amino, hydroxy, chlorine (in nucleus), and methyl.

The mutual effect of two radicles substituted in the chain may give rise to substances of greater toxicity than are produced even by the substitution of one radicle. Thus the combination of chlorine and hydroxy groups in the benzene ring to produce chlorphenol or dichlorphenol is more effective than the substitution of chlorine alone (chlorbenzene) or of hydroxyl alone (phenol). The association of chlorine and the nitro radicle, again, is usually productive of highly toxic compounds, chlorpicrin, for example, but their association in the benzene nucleus usually results in compounds whose toxicity is limited from the insecticidal standpoint, by their low volatility, a factor which also limits the insecticidal value of many other combinations, in particular the nitro-amido, the nitro-aldehyde, and di-nitro associations.

There is no doubt that, generally speaking, a close relationship does exist between the rate of evaporation and vapour pressure of a substance and its toxicity to an insect. In a homologous series of compounds a gradual decrease in vapour pressure and in volatility is accompanied by an increase in

toxicity, but if the vapour pressure sinks too low to allow a toxic concentration, which may be defined as the minimum amount in millionths of a gram-molecule, which when diffused in 1000 c.c. of air proves toxic, then non-toxicity results. Thus, in the aromatic series of hydrocarbons, the vapour pressure value decreases steadily from benzene to naphthalene, and is accompanied by increasing toxicity. Thus, benzene, toluene, and xylene are of low toxicity, pseudocumene and mesitylene are of moderate toxicity, and naphthalene, anthracene, and phenanthrene are relatively non-toxic.

Nearly all organic compounds that boil above 215 degrees C. are uncertain in their toxic effect and those boiling above 245 degrees C. are non-toxic. Substances whose vapour is strongly irritant are usually markedly toxic. Particularly is this the case when the substance is a substitution product. Thus, the introduction of chlorine into the toluene side-chain produces the irritant substance benzyl chloride. Substitution of a nitro-radicle into the chloroform molecule or of three chlorine atoms into the nitro-methane molecule produces chlorpicrin, a strongly lachrymatory compound which is five hundred times as toxic as chloroform and three hundred times as toxic as nitro-methane.

Allyl isothiocyanate, the phenols, chlorphenols, and ammonia derivatives are all sharply irritant and highly toxic.

Certain compounds are particularly poisonous. Such, for example, are the aromatic amido and hydroxy derivatives; (*e.g.* methylaniline, dimethylaniline, o- and p-toluidine, aniline); the former of these would seem to bring about a direct chemical change in the insect tissues.

As regards the toxicity of insecticides to the egg stages of the insects, much remains to be elucidated. It is well known that, in general, insect eggs are extremely resistant to insecticidal treatment. In the case of a great many pests it is practically impossible to destroy the eggs without seriously injuring the plant on which they are laid. An insecticide that is fatal to an egg stage may produce its effects:

(*a*) By forming a hard mechanical coating around the egg which prevents hatching; or

(*b*) By softening or dissolving the outer layer which conserves the moisture content of the embryo, so that the egg is exposed to risk of desiccation; many successful ovicides act in this way, for example, lime-sulphur, lime, and preparations containing phenol;

(*c*) By actually penetrating the egg covering and so reaching the embryo; alkalies are capable of doing this if the

outer layer has first been partially attacked; thus a mixture of bleaching powder and caustic soda, which separately have no lethal action, will attack insect eggs owing to the preliminary action of the bleaching powder upon the outer covering.

(*d*) Or the insecticide may merely remain upon the outside of the egg and kill the emerging larva, as do such substances as nicotine, pyridine, and zinc arsenite.

### Miscibility

The miscibility of a substance, from an insecticidal point of view, may be defined as the relative power it has of remaining suspended in a fluid medium, in the case of a stomach poison, or the readiness with which it may be emulsified, if a contact poison.

Here again no definite standard of comparison exists.

The disadvantages attending the use of a substance which is not in a sufficiently fine state of division may quite outweigh any advantages resulting from a low cost price or high toxic value. A coarse powder cannot be induced to remain in suspension in a fluid for long; unless continuous agitation of the fluid is carried out, the powder sinks to the bottom of the fluid. Such an insecticide tends to clog the spraying nozzles, has poor spreading powers, and, the particles being large and so less rapidly affected by digestion, may be excreted unaltered by a rapid feeder.

A flocculent substance such as freshly precipitated arsenate of lead is therefore easier to manipulate than a coarse crystalline powder such as Paris Green.

A fairly coarsely powdered substance or a substance such as sulphur which has an aversion to water can be more advantageously applied as a dust. Dusting is generally regarded as less efficient than spraying owing to the difficulty of reaching the lower surface of the leaves, but is probably more effective upon feathery foliage, and has the advantage of being applicable on slopes too deep to permit of wet spraying, and in districts where water is scarce. One pound of dust may be regarded as equivalent to two gallons of spray, but the wastage is probably greater. It is essential that the powder used as a diluent or carrier should approximate in specific gravity as closely as possible to the insecticide used, or the heavier powder will sink to the bottom of the container. Diluents and carriers variously recommended are talc, schist, limestone, precipitated chalk, gypsum, kieselguhr, china clay, and silt; slaked lime has a tendency to absorb moisture and clog the machine. The operation may be carried out with

safety, when the foliage is either dry or moist, but to prevent waste should be done on a calm day, or the spraying should be at right angles to the direction of any wind blowing (see Appendix).

The miscibility of a stomach poison is somewhat different from that of a contact poison. In the former case, the problem is to obtain an efficient mechanical mixture of a solid with a fluid; in the latter case, the obtaining of a mechanical mixture of two fluids insoluble in one another is in question.

If an oil be forced into water through the fine rose jet of a syringe it is broken up into minute globules and a mechanical mixture of oil and water results. Such a mixture is extremely unstable. Unless continually agitated, the oil globules aggregate into one connected mass, owing to the great density-difference between the two fluids. If, however, the water holds in suspension solid particles of extreme minuteness, as, for example, oxides of alkali metals, or metallic salts of fatty acids such as soaps, then the particles will form a coating around each oil globule and prevent it from coalescing with its neighbours. A fairly stable mixture of oil and water can thus be produced, such a mixture being termed an *emulsion*. Most precipitates and powders are not sufficiently fine to emulsify oils; the basic sulphates of iron and copper are, however, among the best. If, therefore, it is desirable to obtain a combination between a coarse-grained but effective insecticide such as Paris Green and an oil such as paraffin, it is necessary to add a little sulphate of iron and lime to the Paris Green.

It may be noted that increased miscibility and adhesivity may be obtained for coarse-grained insecticidal substances (Paris Green, lead arsenate, etc.) by coating the particles with an insoluble metallic soap. A solution of a tallow soap is added to a suspension of the insecticide, and a soluble salt of a heavy metal (lead acetate, lead nitrate, copper sulphate) is then added so as to precipitate the lead or copper soap on the particles or insecticide.

These questions of emulsions will be discussed more fully in a later chapter.

### Adhesivity

The sticking power of an insecticide is one of its most important properties, particularly if the insecticide be a stomach poison. Generally speaking, the finer the state of suspension of the substance in the medium, the better its adhesivity; a finely divided precipitate such as lead arsenate, for example, scarcely requires the addition of an adhesive,

as owing to its flocculent condition it settles into the very tissues of the leaf and when once fully dry can never be completely washed off by rains, whereas a comparatively coarse crystalline powder, such as a copper compound, is very quickly washed off from the leaves if used without the addition of a sticking agent, especially upon plants with a very smooth or a waxy foliage.

Moore (1921) has suggested that the imperfect powers of adhesion of such substances as lead arsenate, calcium arsenate,

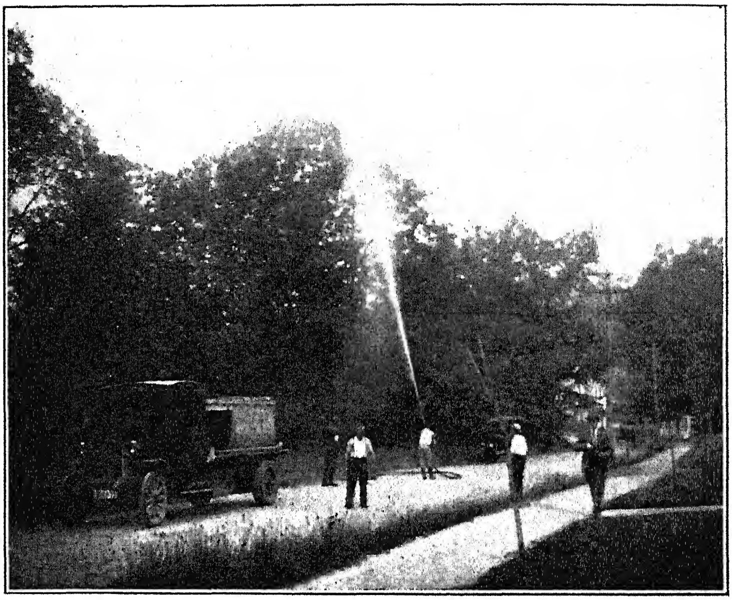


Fig. 6.—Power spraying against the Gipsy Moth, Franklin, N.H., U.S.A., by U.S. Dept. of Agriculture (Bureau of Entomology).

or Paris Green are probably connected with the fact that their particles carry a negative electric charge, and that the particles of a wet leaf surface also carry a negative electric charge so that wash and leaf surface tend to repel one another. It is possible, therefore, that if some substance such as ferric hydroxide or aluminium hydroxide, whose particles are electro-positive, be added to such washes, or that if arsenicals whose particles are electro-positive, such as ferric arsenate or arsenite, or aluminium arsenate and arsenite, were used, better powers of adhesion would be found to result.

Substances recommended as adhesives include *soap*, *molasses*, *glue*, *size*, *glucose*, *resin*, *gelatine*, *saponin*, and

*sodium silicate*, the proportion used being 1-2 per cent of the final wash.

Smith (1908), for example, suggests for use upon cabbages and similar waxy foliage the following:

STOCK SOLUTION

| | |
|---|---|
| Pulverised resin | 5 lbs. |
| Concentrated lye | 1 lb. |
| Fish oil | 1 pint. |
| Water | 5 gals. |

The oil, resin, and one gallon of hot water are boiled together in an iron kettle until the resin is thoroughly softened. The dissolved lye is slowly added, the mixture being continually stirred. Four gallons of hot water are added, and boiling is continued for two hours until the liquid is clear and amber-coloured. This stock solution is used in the proportion of 5 per cent for the final wash. For example:

| | |
|---|---|
| S.S. | 1 gal. |
| Water | 16 gals. |
| Milk of lime | 3 gals. |
| Paris Green | $\frac{1}{4}$ lb. |

A resin stock solution has also been suggested by Lefroy (1915), made by boiling 8 lbs. of resin in a solution of 8 lbs. of washing-soda in 10 gallons of water. This solution can be used advantageously with creosote oil (1 gallon to 40 gallons of oil) as a winter wash, or in similar proportion with lead arsenate as a stomach poison.

Lafforgue (1914) recommends the employment of saponin in copper sulphate sprays; it can be used even in slightly acid or neutral solutions, facilitates emulsification of bodies insoluble in water, such as oils, etc., but does not interfere with the solubility of copper salts, so that the resultant sprays keep their immediate intensity of action.

Lees (1915) has experimented with a number of adhesive substances in an effort to find a winter wash more adhesive than limewash. *Flour*, *glue*, and *size* he finds too expensive, and *glue* is soluble in water and apt to get washed away by rain, although the addition of a little potassium dichromate renders the glue insoluble after exposure to light. *Sodium silicate* is not effective if lime be present, owing to conversion into calcium silicate. He therefore suggests a formula containing lime, glue, starch, potassium dichromate, and water, *e.g.*:

| | | |
|---|---|---|
| Lime | 20 | per cent. |
| Glue | 1-1·5 | ,, |
| Starch | 1-1·5 | ,, |
| Dichromate | 0·6 | ,, |
| Water | 77 | ,, |

The use of glue has been strongly recommended by Masino (1917) to increase the adhesivity of Bordeaux Mixture. It would seem to modify the chemical composition of the wash somewhat, since the precipitated copper hydroxide dissolves and combines with the glue, the change of colour to deep violet suggesting the action of the glue as a weak organic acid.

The **wetting** and **spreading** powers of an insecticide are frequently confused, but the two terms are not synonymous.

The *wetting power* represents the degree of adhesion between the wash and the solid—that is to say, the surface of the leaf or insect. Such adhesion is often only produced by an actual dissolution of the leaf surface or insect surface ; thus, certain kinds of foliage with a waxy surface, or such insects as Apple Sucker (*Psylla mali*) or Woolly Aphis (*Eriosoma lanigera*), protected by a waxy secretion, are impervious to water, but can be wetted by a fat solvent such as creosote, acetone, or a paraffin.

The wetting power, therefore, will vary according to the physical state of the surface that is to be wetted, and it is possible for solutions with different surface tensions to have equal wetting power.

*Spreading power*, on the other hand, represents an excess of adhesion over the *cohesion* of the liquid—that is to say, over the interfacial tension between that liquid and air. The degree to which adhesion exceeds cohesion will determine the extent to which the liquid, instead of forming droplets, will spread as a film over the surface of leaf or insect, or penetrate the interstices of a folded bud or insect tracheae.

Now, the adhesion is inversely proportional to the interfacial tension between liquid and solid, between the spraying solution and the leaf or insect ; that is to say, the lower the value of such interfacial tension, the greater the degree of adhesion. It follows, therefore, that if the interfacial tension between liquid and solid be at a minimum, the adhesion will be at a maximum ; if, in addition, the cohesion or interfacial tension between liquid and air be at a minimum, the excess of adhesion over it—that is to say, the *spreading power*—will be at its maximum also.

Now, in practice, the adjustment of the I.T. between wash and solid is not practicable. It would have to be made afresh for each particular type of insect and foliage that the wash was required for, and the vogue of specific washes is over ; the demand nowadays is for general utility washes. The I.T. between wash and air is, however, readily measurable and holds good for a particular strength of wash, whatever the purpose. This I.T. for any particular wash can be brought

almost to a minimum by the addition to the wash of certain substances. Oil emulsions, for example, have a lower I.T. than water; solutions of certain soft soaps or Castile soaps have a lower I.T. even than oil emulsions.

Spreading power is dependent, however, upon other factors besides interfacial tension. In the first place, it will be obvious that unless there is considerable adhesion between wash and solid there can be no spreading. Nearly always the leaf surface is coated with a greasy or a waxy layer, so that it is essential that the wash should have a solvent action upon this layer. If there be absolutely no affinity between the waxy layer and the insecticide there can be neither spreading nor wetting.

The addition to the wash of some substance which is similar in chemical constitution to the leaf surface, however, will induce the spray mixture to form a film of liquid over the leaf. Thus the addition of such compounds as beechwood creosote, carvacrol, or amyl alcohol will induce the wash to spread over waxy leaves such as those of the cabbage; the addition to a wash of certain proteins and plant infusions will induce spreading upon leaves with a surface of cellulose, such as those of plum or citrus (Moore, 1921).

Secondly, there is the phenomenon known as *surface concentration.* Certain substances, saponin and gelatin for example, when in solution, instead of diffusing equally throughout the solvent, tend to concentrate in the upper layers of the liquid. Thus in a 0·25 per cent solution of sodium glycocolate, the degree of concentration in the thin surface layer is about 160 times that of the bulk. The result of such surface concentration is a peculiar viscosity or rigidity at the surface of the solution, and Vermorel and Dantony (1912) have shown that liquids with such high surface viscosity possess marked wetting powers. Thus the wetting power of solutions of saponin or gelatin, substances whose surface tension is comparatively high, seems to be due to their ability to form liquid planes, the high surface viscosity of which prevents rupture and consequent running together of the surface layer to form drops.

This phenomenon explains why the wetting power of a soap solution is in direct proportion to the amount of soap in the solution, up to a certain point, although the surface tension is the same whatever the concentration. That is to say, an increase in the strength of a soap solution does not decrease the surface tension but does increase the surface viscosity, and so increases the wetting power. Solutions containing 10 per cent, 1 per cent, and 0·1 per cent of oleic

soap, respectively, all possess practically the same surface tension. If their wetting power be tested by their ability to form a continuous film on a piece of greased paper, it will be found that the 10 per cent and 1 per cent solutions will give a positive result, whereas the 0·1 per cent solution entirely fails to wet (Cooper and Nuttall, 1915).

There is a third factor concerned in this question of spreading power, this time an inimical one, one that retards or reduces it, and this is the *viscosity* or "internal friction" of the wash. Although not influencing the *extent* to which a liquid may spread, it does affect the *rate* of spreading. Compounds with a viscosity equal to or higher than castor-oil, for example, are nearly always poor insecticides, and it is possible that a liquid may be so viscous as to be valueless as an insecticide (Moore and Graham, 1918).

An ideal insecticide, therefore, will contain in addition to the toxic ingredient some substance such as soap or gelatine to facilitate spreading power and some substance such as creosote or acetone to promote wetting power. The ingredients should be cheap and readily procurable. It must be easily preparable, must be adhesive enough to remain upon general types of foliage even in wet weather, and the toxic ingredient should be either completely insoluble in the liquid medium or readily emulsified.

The classification of insecticides is somewhat arbitrary. By most authors, the following classes are recognised: (1) **Stomach poisons,** (2) **contact poisons,** (3) **fumigants,** (4) **insectifuges,** (5) **dipping fluids.**

It is not convenient from the point of view of discussion to separate stomach poisons and contact poisons too rigidly; generally speaking, the former class comprises *metallic compounds*, the latter class comprises *alkalies*, *paraffins*, *phenols*, and *soap*. On the other hand, certain of the alkaloid substances such as *nicotine* may act either as stomach or as contact poisons, and in any case the toxic action of the majority of insecticidal compounds is somewhat obscure.

In the following pages, therefore, the compounds comprising stomach poisons and contact poisons will be discussed alphabetically in chemical groups—arsenicals, alkalies, alkaloids, and so on—irrespective of their mode of action. Fumigants, insectifuges, and dipping fluids will be, for convenience, discussed in separate chapters.

# CHAPTER VII

## INSECTICIDES—*continued*

### Arsenical Compounds

THE arsenical compounds used as insecticidal sprays upon plants are the *orthoarsenates* of *calcium, iron, copper, lead, sodium,* and the *arsenites* of *copper, calcium,* and *sodium,* all of which, with the exception of the sodium compounds, possess, in addition to their well-known high toxicity, the property of being comparatively insoluble and stable in water; sodium arsenate, on the other hand, being soluble, cannot be used upon foliage, but is of value as a basis of preparation for the others. Of the above compounds, the calcium arsenate is the most toxic, and lead arsenate, with only half or less than half of the arsenic content of others, comes second owing to the lead constituent being also poisonous.

The toxic value of these compounds is, however, greatly modified by the presence of impurities, in the form either of soluble arsenical salts or of chlorides and alkalies, which may render the compound soluble in the medium. As most arsenates are soluble to some extent in an alkaline solution or a solution of chlorides, the purity of the chemicals and of the water is a serious matter. The presence of soluble arsenic in greater quantity than 2 per cent of the arsenical substance used almost invariably produces foliage injury, the extent of damage varying according to the amount of soluble arsenic present, to the susceptibility of the plant, and to the weather conditions.

The toxicity of various arsenical compounds, again, may not depend directly upon the relative amounts of arsenic present, but upon the form of the arsenate. Lead hydrogen arsenate, which has an arsenic oxide value of 33 per cent, is found by Lovett and Robinson (1917) to have a toxicity, at a given dilution, higher not only than that of basic lead arsenate, which has a lower arsenic oxide value, but higher also than that of calcium arsenate, which has a higher arsenic oxide value. The arsenic devoured by insects feeding upon sprayed foliage

is not all assimilated, for a considerable amount is passed out unchanged with the excrement. In the case of lead hydrogen arsenate most of the arsenic devoured was recovered from the insects' tissues, whereas in the case of basic lead arsenate most of the arsenate ingested was found in the excrement. Apparently the toxicity of an arsenical salt upon an insect is not in proportion altogether to its water-solubility, although certainly the sodium salts, whose solubility is high, are extremely toxic, but is dependent rather upon its solubility within the body of the insect, and this is a question which involves the stability of the compound.

The earliest arsenical preparations to be used as insecticides were *London Purple* and *Paris Green*, owing to the fact that, being extensively used as dry colours, they were easily procurable, comparatively cheap, and in a fairly high state of division. On the other hand, they possessed one important drawback: the percentage of impurity in the form of soluble arsenical compounds and of chlorides was considerable. *London Purple*, a by-product in the manufacture of magenta, and a mixture chiefly of the arsenate and arsenite of calcium, is particularly variable in composition, and so in spite of its cheapness soon fell into disuse.

**Paris Green**, however, has retained much of its earlier popularity, in spite of its liability to scorch foliage, its poor adhesivity, and its tendency to settle rather than to remain in suspension. It is a double arsenite and acetate of copper, containing when pure the equivalents of 55-60 per cent of arsenious acid, 27-31 per cent of copper oxide, and 10 per cent of acetic acid. It is soluble in ammonia and in certain alkalies, but if pure is almost completely insoluble in water. Unfortunately, it generally contains soluble impurities such as sodium arsenite and arsenious oxide. The proportion of such impurity ought not to exceed 2 per cent.

Although used alone very often, at the rate of one pound per two hundred gallons, it is very liable to scorch foliage, particularly if used in hot sunny weather or on tender-leaved plants such as tomato or peach. The bulk of soluble arsenic present, however, can be neutralised by conversion into calcium arsenite if freshly slaked lime be added, at the rate of two parts of lime to one of Paris Green by weight, and the substance can be used at the rate of one pound to 125 gallons on all orchard fruits except peach; one pound to 50 gallons on potatoes; but the scorching effect, though greatly reduced, is not eliminated entirely.

Freshly precipitated acetoarsenite of copper is fine enough to remain suspended in water, but the commercial product is

crystalline and heavy, requiring constant agitation to keep it suspended; the coarse particles do not cover the leaf surface very well, nor are they acted upon very quickly by the digestive juices of the insect, but tend to pass through the alimentary canal unaltered.

### Lead Arsenate

The disadvantages of Paris Green have brought the use of lead orthoarsenate as a stomach poison into general favour. Though more expensive than Paris Green, it is preferable in many respects: it can be readily prepared as a chemically pure flocculent precipitate possessing good adhesive and covering powers; its solubility in water is so slight as to be almost negligible; it is sufficiently finely divided to remain suspended in water for a considerable time without the need for stirring, and is sufficiently fine to emulsify paraffins.

The substance is generally prepared by the interaction between lead acetate or lead nitrate and sodium arsenate, but there is much variance of opinion as to the proportions that should be taken of each. This is a matter of some importance, for excess of sodium arsenate may produce severe scorching, and excess of lead acetate, though less serious, may do the same.

The chemistry of lead arsenate preparation has been discussed by Pickering (1906) and by Robinson and Tartar (1915). Arsenates are of three types, according to the relative proportions of metallic oxide and arsenic oxide. Thus in the case of the sodium salts we have:

The *metarsenate*, $Na_2O,As_2O_5$, or $NaAsO_3$, with 78·77 per cent of $As_2O_5$.
The *pyroarsenate*, $2Na_2O,As_2O_5$, or $Na_4As_2O_7$, with 64·97 per cent of $As_2O_5$.
The *orthoarsenate*, $3Na_2O,As_2O_5$, or $Na_3AsO_4$, with 55·29 per cent of $As_2O_5$.

The arsenates used as insecticides are *orthoarsenates*.

The last two may have part of the sodium replaced by hydrogen; thus we may have:

*Monosodium orthoarsenate*, $NaH_2AsO_4$, with 70·12 per cent of $As_2O_5$.
*Disodium orthoarsenate*, $Na_2HAsO_4$, with 61·82 per cent of $As_2O_5$.
*Trisodium orthoarsenate*, $Na_3AsO_4$, with 55·29 per cent of $As_2O_5$.

Commercial sodium arsenate is the disodium *orthoarsenate*. This is sold commercially either as the crystallised salt, the hepthydrated salt ($Na_2HAsO_4 . 7H_2O$), although the dodecahydrate ($Na_2HAsO_4 . 12H_2O$) may also occur, or as the anhydrous salt ($Na_2HAsO_4$). The crystallised form is usually commercial pure, but the anhydrous salt often contains pyroarsenate, metarsenate, and free arsenic acid. It is listed as *crude*, *commercial*, or *dry* arsenate.

According to Pickering, it is advisable to have slight excess

of the lead salt in order to make sure that all the sodium arsenate is neutralised. The anhydrous arsenate is preferable, though impure, as weight for weight it is three times cheaper than pure arsenate, and the lead arsenate made with it is in a far finer state of division than that made with the crystallised salt. Proportions recommended are:

3·5 parts of acetate to 1 part of anhydrous arsenate.
2 parts of acetate to 1 part of crystallised arsenate; or
$2\frac{1}{2}$ parts of nitrate to 1 part of anhydrous arsenate.
$1\frac{1}{4}$ parts of nitrate to 1 part crystallised arsenate.

These reactions yield the *basic* or *triplumbic lead arsenate* ($Pb_3(AsO_4)_2$), which, as previously pointed out, has less killing power than the *hydrogen arsenate* of lead owing to the lesser percentage of arsenic oxide content, and also, being heavier, has less power of suspension.

It would seem preferable, therefore, to use *two* parts of lead acetate to one part of anhydrous arsenate, as this would give the hydrogen or *diplumbic* arsenate, $Pb_2H_2(AsO_4)_2$. This salt would probably have a greater percentage of soluble impurity than the basic salt, and would require more discrimination in its use.

The difficulty of preparing home-made lead arsenate renders it distinctly advisable for the user to leave the preparation of it to the chemical manufacturer. The arsenate of lead now on the market for spraying purposes is chiefly in the paste form, the various proprietary brands differing greatly in percentage of arsenic. A good paste should contain not less than 50 per cent of lead arsenate and not more than 2 per cent of soluble impurities. It will be found generally to be a mixture of hydrogen arsenate and basic arsenate. The paste, if stored, should be kept covered with water and precautions taken against frost.

Lead arsenate is much less toxic than Paris Green, so that three to four times the amount per hundred gallons of water is required for its use. If paste be used, *six pounds per hundred gallons* will generally suffice, or *four* pounds per hundred gallons if for use on tender foliage. If the powder be used, only half the weight as of paste is required, but it is advisable to add *ten* pounds of slaked lime to each *three* of arsenate as a precaution against scorching.

Bordeaux Mixture may safely be used as a medium instead of water, the same proportion of arsenate to the medium being used, but the toxic action of the arsenate is probably reduced by nearly one-half; or nicotine solution may be used as a medium, although whether the efficacy of either nicotine or arsenic is increased is doubtful.

The use of lime sulphur as a medium is not advisable. If used with the hydrogen arsenate, the consequent precipitation of free sulphur and lead sulphide clogs the spraying nozzles and interferes with the agitation of the liquid, and the formation of soluble mono-calcium-arsenate may induce foliage injury. The use of lead arsenate with potassium or sodium sulphides is always dangerous to foliage owing to the formation of soluble arsenates, and for similar reasons the addition of soap is not to be recommended.

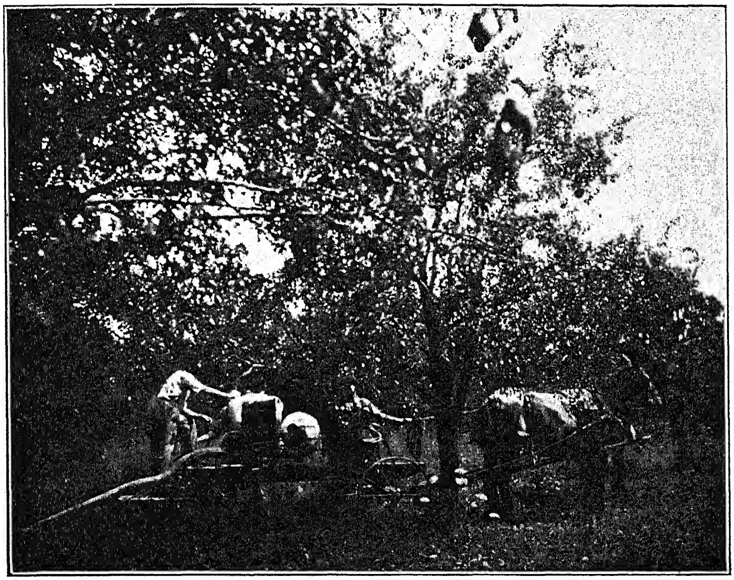


FIG. 7.—Power dusting against the Pear Psylla, Geneva, N.Y., U.S.A., by N.Y. State Dept. of Agriculture (Geneva Expt. Station).

### Calcium Arsenate

The unsatisfactory nature of combinations of lead arsenate or Paris Green with contact washes such as lime-sulphur, and the general demand for such a combination, have brought the use of calcium arsenate to the fore. The effect of war conditions upon the supply and price of lead arsenate has also tended towards the use of this substance. Although cheaper than the lead salt, its use has generally been deprecated in the past owing to its dangerous effect upon foliage, caused by the large proportion of free caustic alkali in the commercial product, by a certain extent of solubility in water, and by the

affinity of the calcium constituent for carbon dioxide leading, in the presence of carbon dioxide from the leaf surface, to the liberation of free arsenic acid.

The substance is, however, practically insoluble in lime-water, and is thus eminently suitable for admixture with Bordeaux Mixture, or even with lime-sulphur or soluble sulphides, if excess of lime be present. In fact, for use in alkali sulphide and polysulphide solutions, calcium arsenate is probably superior to all other arsenical preparations, since there would seem to be no chemical interaction between the arsenate and the polysulphides. According to Robinson (1918), there is no apparent reaction between either the calcium hydrogen arsenate or the tricalcium arsenate and lime-sulphur when used at the usual spraying dilution, but some commercial substitutes reacted with both the arsenates. If organic acids or chlorides be present in the water, some arsenic may go into solution, but the addition of excess of calcium oxide, say 2 or 3 lbs. of hydrated lime to each pound of calcium arsenate, to the wash would prevent this.

The arsenate is prepared as follows: 55 lbs. of unslaked lime (90 per cent CaO) is slaked gradually, beginning with a small amount of water. When slaking is well under way, 100 lbs. of anhydrous sodium arsenate (65 per cent $As_2O_5$) dissolved in hot water should be added and the mixture stirred until the lime is thoroughly slaked. Three to three and a half times as much water as lime will be required for slaking; say 20 gallons. The resulting calcium arsenate should have an arsenic oxide content of 15 per cent. Filter and dry, as far as possible. If the commercial dry powder be used it should be so fine that 1 lb. occupies 80-100 cubic inches, and should contain the equivalent of 45 per cent of arsenic pentoxide in the form of tricalcium arsenate; the amount of soluble arsenic should not exceed 0·75 per cent. Calcium arsenate may be used at the rate of *two pounds per forty gallons* of lime-sulphur or Bordeaux solution, as the salt contains the same percentage of arsenic oxide as is found in standard arsenate of lead paste, namely 15 per cent.

With sodium sulphide solution, ½ lb. to 40 gallons is sufficient, and it is advisable to add 10 lbs. of hydrated lime to each 40 gallons.

Calcium arsenate has come into great favour during the last few years as an insecticidal dust, particularly for application to potatoes, tobacco, and cotton.

Against the Cotton Boll Weevil (*Anthonomus grandis*) the use of undiluted calcium arsenate as a dust is one of the few measures that have yielded good results. According to Coad

and Cassidy (1920), the aim of poisoning the weevils is not complete extermination of them, such a result being impossible, but the idea is so to reduce the infestation as to permit the maturation of a full crop of cotton. Normally, a cotton plant produces more fruit than it is able to mature, some 60 per cent of the squares failing to become bolls, and being shed during their development. Up to this point, therefore, fruit-shedding due to weevil attack merely takes the place of the normal shedding which would occur if the weevils were absent. Generally speaking, therefore, the weevils are allowed to multiply until they have become sufficiently abundant to puncture more squares than would be shed normally. When the percentage of weevil-punctured squares reaches 15-20, the crop is dusted with calcium arsenate at the rate of 5-7 lbs. per acre. The operation is carried out at night with the aid of special dusting machinery (see Appendix). The dusting is repeated sufficiently often to prevent the infestation rising above 25 per cent, until the plants have had time to develop beyond weevil injury. The effect of the poison does not last long, but intervals of four to five days between successive dustings are usually found to be sufficient. It was formerly considered that the insect took in the poison when drinking dew or rainwater which collects on the plants, but the present opinion somewhat favours the view that the weevil ingests the poison with its food, so that the dust should be applied particularly to the squares, bolls, and terminal buds rather than to the foliage.

In Canada and U.S.A. calcium arsenate is also coming into use, particularly upon apples, as the chief constituent of the so-called "copper-arsenic" dust. The dust contains usually 85 per cent of hydrated lime, 10 per cent of finely ground copper sulphate, and 5 per cent of calcium arsenate.

**Sodium Arsenate** is too soluble and contains too much free chloride to be safely used as an insecticide upon foliage, and is chiefly used as a basis for the preparation of home-made lead arsenate. Combined with Bordeaux Mixture it has been used with success upon potatoes, and a mixture of 5 to 10 per cent solution of sodium arsenate with paraffin emulsion has been used successfully against Longicorn beetles.

In addition to the metallic compounds of arsenic acid, certain similar salts of *arsenious acid* are sometimes used.

**Arsenious Oxide,** the ordinary "white arsenic" of commerce and the basis for the commercial manufacture of other arsenical salts, is the most concentrated form in which to buy arsenic, and the cheapest. From an insecticidal standpoint, however, it has certain grave disadvantages: it has poor powers of

suspension, its toxic efficiency is low, and it is liable to scorch foliage.

According to Sanders and Kelsall (1922), however, these difficulties do not occur when arsenious oxide is used in Bordeaux Mixture instead of in water. They recommend the use of finely ground superfine white arsenic. A mixture of 1 lb. of arsenic with 1 lb. of slaked lime (high-grade calcium oxide) is sifted into 10 imperial gallons of water; the lime induces the arsenic to go into suspension. The liquid is well stirred, and a bag containing 10 lbs. of copper sulphate crystals is suspended in it, the liquid being stirred from time to time. The solution must be made at least twenty-four hours before it is required, but once made will keep indefinitely.

This stock of copper-arsenic solution is used in the preparation of the Bordeaux Mixture just as if it were an ordinary solution of copper sulphate and in the same proportion, namely for potatoes according to the formula 4-4-40, and for apples according to the formula 3-10-40 (see Bordeaux Mixture).

**Sodium Arsenite**, being extremely soluble in water, cannot be safely used alone upon plants, although valuable as the chief constituent of animal dips and poison baits. It is used to some extent with Bordeaux Mixture as a cheap substitute for Paris Green, but even thus it is not possible to eliminate the propensity to foliage injury, although the risk can be minimised to some extent by adding the arsenite to the copper-sulphate solution rather than to the completed Bordeaux Mixture.

Arsenite of sodium is generally prepared by adding 2 lbs. of arsenious acid and 4 lbs. of washing-soda to a gallon of boiling water, and boiling for fifteen minutes until the liquid is clear. This solution is diluted to 2 gallons and used as stock, 1 to 3 pints per 50 gallons of Bordeaux Mixture being the usual proportion.

**Calcium Arsenite** is also used as a cheap substitute for Paris Green for mixing with Bordeaux Mixture, or, being comparatively insoluble in water and having good powers of suspension, is sometimes used alone.

It is prepared by the interaction of lime and arsenious acid. Theoretically, 2 lbs. of good quicklime should suffice to neutralise 1 lb. of arsenic, but in practice it is better to use 4 lbs. Slake the lime and arsenic together to form a smooth paste, stirring well to ensure perfect mixture; dilute to 3 gallons and boil for forty minutes after boiling-point is reached. Another method is to use sodium arsenite, prepared as described above, adding it to limewater at the rate of 1 pint to a solution of slaked lime (2 lbs. per 2 gallons water). Dilute to 40 gallons.

Calcium arsenite, being theoretically twice as powerful as Paris Green, should be used accordingly, 1 lb. sufficing for 300 gallons of water, where 1 lb. per 150 gallons for Paris Green is recommended. It is safer when used in Bordeaux Mixture.

**Copper-Aceto-Arsenite,** or Paris Green, has been already discussed.

**Copper Arsenite,** Scheeles Green, results from the precipitation of a solution of sodium arsenite with a solution of copper sulphate. It is a more insoluble salt than Paris Green, is not in crystalline form, and the precipitate when freshly prepared is finer and has better powers of suspension. Copper arsenite is cheaper than Paris Green and quite as effective, but does not seem to have gained the confidence of agriculturists and is little used.

A formula used in France recommends the dissolution of 1 lb. of arsenious acid and 1 lb. of soda ash (anhydrous sodium carbonate) in 1 gallon of boiling water. Add, whilst stirring continuously, a solution of 10 lbs. of copper sulphate crystals in 10 gallons of water. Then add milk of lime (10 lbs. of lime in 10 gallons water). If further adhesiveness is required, molasses may be added, 10 lbs. to each gallon. Dilute to 100 gallons for use. This preparation is thus Bordeaux Mixture with a little Scheeles Green.

**Zinc Arsenite** has been put on the market in paste form, and the paste is claimed by the manufacturer to contain at least 40 per cent of arsenious oxide content, and less than 1 per cent of soluble impurity. Morris and Parker (1914), in Montana, have used zinc arsenite successfully against Codling Moth at the rate of 12 oz. per 50 gallons of water, and other observers report successful admixture with Bordeaux, 2 lbs. of paste to 50 gallons of Bordeaux upon potatoes. Unfortunately, it seems liable to scorch the foliage of stone-fruits, particularly if in combination with Bordeaux Mixture or other washes.

### Legislation concerning Arsenicals

There is no doubt that in countries other than the U.S.A. there is a certain amount of prejudice against the use of arsenical insecticides, particularly against their use upon vegetables and fruits, and there is considerable opposition from beekeepers. Their use, however, is authorised in England, Austria, Belgium, Greece, Holland, Portugal, and Sweden, and no regulations whatever concerning them exist in Germany, Denmark, Spain, Hungary, Italy, Russia, and the United

States. In France, however, the Ministry of Agriculture, by an Order dated 15th September 1916, has forbidden the sale and use of soluble arsenical salts, and so restricted the sale and use of the insoluble compounds as to handicap seriously any one wishing to use them. They can be sold only by licensed traders; sold only in metal tins bearing the name of the vendor, and sold only when mixed with a coloured and odoriferous substance such as 2 per cent pyridine, crude phenol, nitro-benzene, etc.; all sales must be recorded. They cannot be used for market gardens or forage crops, for weed destruction, nor on vines after flowering, nor on fruits except apple, pear, and plum, nor even on these during blossom-time.

Lead arsenate and calcium arsenate cannot therefore be made on the spot by mixing soluble sodium arsenate or lead acetate, but have to be purchased in the more expensive paste form.

Considerable protest against these restrictions has, of course, been made by French and Algerian vine-growers, for the soluble sodium salts have been in use for many years against vine pests and no evil results have ever accrued.

Extensive analyses of grapes, wine, and wine pressings collected from all vine-growing districts and in exceptionally dry seasons have shown no trace of arsenic in wines, and only very slight traces in the pressings and grapes.

In America it has been calculated that of cabbages sprayed with an arsenical preparation, a person would have to eat twenty-eight at a meal to obtain a toxic dose; of potatoes, several 26-gallon barrels would be necessary. Fruit in a country with a normal rainfall is generally safe enough after the lapse of three weeks from the last date of spraying.

### Copper Compounds

The toxicity of salts of copper is directly proportional to their solubility. It has been already pointed out, however, that solubility of the toxic ingredient of a stomach poison is a disadvantage owing to the scorching effect produced upon foliage. It has been asserted, however, that in the case of copper sulphate scorching of foliage is brought about not by the dissolved copper salt but by the presence of free acid in the solution, and that such scorching effect can be obviated by rendering the solution exactly neutral by addition of sodium carbonate (0·9 per cent by weight). The slightest acidity will produce scorching.

There is another disadvantage attendant upon the use of a soluble salt, and that is its liability to become washed off the foliage by rain. It is preferable, therefore, to utilise the less

soluble salts of copper, such as the hydrate or carbonate or basic sulphate; and as copper sulphate is the cheapest commercial form of copper, it is usual to employ it as a base and by combination with lime or sodium carbonate to obtain the less soluble salts. This principle is carried out in the manufacture of the well-known fungicides, *Bordeaux* and *Burgundy Mixtures*. These preparations are universally used in combination with insecticides, so that some discussion of their chemistry and manufacture is imperative.

**Bordeaux Mixture**, generally speaking, consists of certain insoluble copper salts obtained by precipitation of a solution of copper sulphate with excess of lime. As to the exact composition of the salts that are thus precipitated, great controversy exists.

The reaction between lime and copper sulphate is complex. According to the relative amount of lime used, the product will be *acid, neutral,* or *basic,* and in addition to calcium sulphate a number of copper compounds are produced, either basic sulphates of copper, double sulphates of copper and calcium, or double hydrates of copper and calcium.

Bordeaux Mixture is *acid* as long as the proportion of lime to copper is less than 1 : 6. Only the basic sulphate of copper ($5CuO,SO_3$) will be produced.

If the ratio of lime to copper is 1 : 6, all the copper is rendered insoluble by conversion into tetracupric sulphate ($4CuO,SO_3$), and the mixture is *neutral* and has no excess of lime. Proportions between 1 : 6 and 1 : $4\frac{1}{2}$ produce a neutral mixture with excess of lime, the pentacupric and decacupric sulphates being formed.

Proportions greater than 1 : $4\frac{1}{2}$ lead to the production of a permanent *alkaline* Bordeaux Mixture containing a double sulphate of copper and calcium; or if the lime be greatly in excess, a double hydrate of copper and calcium.

The neutral Bordeaux Mixtures, prepared by adding lime to copper sulphate until blue litmus paper ceases to redden or until red litmus paper begins to turn blue, are mixtures containing a more or less considerable excess of lime, and contain calcium sulphate; and with slight excess of lime, the decacupric sulphate ($10CuO,SO_3$) or the double sulphate of copper and calcium ($10CuO,SO_3 : 4CaO,SO_3$); with great excess of lime, the double sulphate of copper and calcium ($10CuO,SO_3 : 10CaO,SO_3$). That is to say, the so-called neutral mixtures are in reality very often alkaline, and the so-called "acid Bordeaux Mixture," prepared by adding 0·1 per cent $CuSO_4$ to a "neutral mixture," is generally a neutral mixture containing excess of lime.

The relative efficacy of *acid mixtures* and *alkaline mixtures*—that is to say, between mixtures of basic sulphates and mixtures containing hydrates and double sulphates—has long been an unsettled question.

The *acid mixtures* contain more copper in solution, but this, on application, is readily converted into the somewhat insoluble carbonate. On the other hand, *alkaline mixtures*, though not containing as much copper in solution at first, gradually yield a considerable amount when exposed to the air. The opinion seems to be that the value of Bordeaux Mixture is more or less proportional to the quantity of tetracupric sulphate present, as, of all the basic sulphates of copper, this one yields the biggest proportion of free cupric sulphate when acted upon by atmospheric carbon dioxide. Accordingly, the most efficient mixture would appear to be the chemically neutral one—that is, a mixture containing 0·1685 part of lime to 1 part of copper sulphate. Any excess of lime beyond these proportions would seem to be so much loss of efficiency and so much waste of money.

However, the general opinion of plant pathologists, horticulturists, and practical farmers seems to be against the use of neutral Bordeaux and in favour of the ordinary Bordeaux containing excess of lime, the most generally accepted formula in practice being the 4-4-40 formula—that is to say, 4 parts copper sulphate, 4 parts lime, 40 gallons of water.

Whatever formula be adopted, certain points are essential to the production of the mixture:

1. The sulphate should be of 98 per cent purity.
2. The quicklime should be freshly burned ; air-slaked lime is useless.
3. The two constituents should be diluted with water as much as possible, consistent with the formula, before being mixed together.
4. The mixture should be freshly made, but stock solutions of sulphate and of milk of lime can be kept.

Ready-made Bordeaux Mixture can be obtained in proprietary form either as a paste or as a powder, but cannot be recommended, owing to its low adhesivity and its low power of remaining in suspension.

**Burgundy Mixture** is a suspension of copper carbonate in a solution of sodium sulphate, and is prepared by the addition of a solution of sodium carbonate to one of copper sulphate. Though used extensively as a fungicide, it is rarely employed against insect pests and need not be discussed here.

### Alkalies

The application of caustic alkalies to plants can be carried out only upon dormant wood owing to the injurious effect of such substances upon foliage. They are used, therefore, chiefly as winter or *cover washes* in order to remove mosses and lichens and to destroy insect eggs. Such a cover wash must fulfil certain requirements; it must give a thick covering, should be cheap, should be easy to mix, and should not be affected by rain.

The alkaline wash generally recommended is a 1 per cent solution of caustic soda containing 1 per cent potassium carbonate, believed to be fatal to insect eggs, and 0·5 per cent of soft soap to render the wash adhesive. The injurious effect of this wash upon insect eggs is doubtful, and no advantage seems to be derivable from the addition of potassium carbonate; a 2 per cent solution of caustic soda is cheaper and more effective. Such washes, however, whilst not necessarily toxic to insect eggs, do tend to glue such eggs to the bark and thus impede or prevent hatching, so that adhesivity and viscosity would seem to be important requirements. Lees (1915) has suggested the following as an ideal cover-wash formula: lime 2 lbs., glue 2 oz., farine 2 oz., potass. dichromate $\frac{1}{4}$ oz., per gallon of water.

According to Pickering (1906), actual destruction of insect eggs can be effected if the alkali wash be emulsified either with soft soap, in greater proportion than in the original formula, or with paraffin emulsion of a certain strength. Thus the addition of 2-3 per cent soft soap to a 2 per cent solution of caustic soda brings about a 70 per cent mortality of the eggs, but such a wash is not practicable on a large scale owing to the precipitation of soap curds by the alkali and the consequent semi-solidification of the emulsion.

A combination of caustic alkali with paraffin emulsion known as *Woburn Wash*, containing ·2 per cent caustic soda, $\frac{1}{2}$ per cent soft soap, paraffin by volume 6 per cent, has also been found to give good results, but here again the precipitation of hard soap by the alkali renders the emulsion unstable and necessitates constant agitation of the mixture during use.

Accordingly, in preparing an emulsion containing caustic alkali, the use of some emulsifying agent other than soap is highly desirable. Pickering has suggested the basic sulphates of copper and iron as suitable for the purpose. A basic sulphate precipitated by caustic soda will, however, not emulsify paraffin so well as one precipitated by lime, so it is advantageous to prepare the emulsion with lime and add the caustic soda later.

A half-pound of iron sulphate is dissolved in nine gallons of water; a quarter-pound of lime is slaked and made into a milk with one gallon of water, and run into the sulphate solution through a piece of sacking. Five pints of paraffin, preferably a high boiling-point oil such as Solar Distillate, are churned into the mixture, and two pounds of caustic soda added.

Copper sulphate may be substituted for the iron salt, and is more effective; but as one and a half pounds are required and half a pound of lime, the cost is greater.

### Alkaloids

The possibilities of using the alkaloidal principles of poisonous plants as insecticides have hardly as yet been investigated; *nicotine*, *quassiin*, *hellebore*, *derris* are, it is true, now in common use as contact poisons and stomach poisons, but little use is made of the insecticidal principles undoubtedly resident in tomatoes, aloes, henbane (*Hyoscyamus*), and wormwood; in aconite and hemlock, in colchicum, and in such fungi as *Amanita muscaria*.

**White Hellebore** (*Veratrum album*) is used to some extent as a stomach poison, either as a suspension, 5-7½ lbs. of finely pulverised roots to 100 gallons of water, or as a dust, diluted with two or three times its weight of flour. It is particularly successful against Gooseberry Saw-fly (*Nematus ribesii*).

**Derris** is the name applied to *Deguelia*, the tropical genus of *Papilionaceae*, the roots of which have long been used as a fish poison, the toxic principle being probably a resin. The raw material is in the form of roots or bark of a plant termed in Borneo "Tuba Ralut," "Tuba tedong," or "Perkakal," ground to powder and extracted with water. It is an effective stomach poison at strength ranging from 1 lb. of powder to 16-128 gallons of water. As a contact poison, with or without soap, it is effective against Aphides, even if so dilute as 1 lb. to 400 gallons of water. It is the basis of several proprietary combination insecticides.

A wash consisting of 1 lb. of derris, 4 oz. of soap, to 1 U.S. gallon of water, is recommended by Wells, Bishopp, and Laake (1922) for application to the backs of cattle infected with Warble-fly (*Hypoderma*), and is claimed to kill all the larvae in the swellings. It has been used successfully also as a powder, mixed with an equal weight of maize starch, against Anoplura, Mallophaga, and fleas on domestic animals, but seems somewhat inferior for this purpose to sodium fluoride.

**Nicotine** is obtainable commercially in the form of tobacco

extract containing free nicotine, or as nicotine sulphate. In the British Isles, where economic difficulties and excise restrictions discourage the growth of tobacco for insecticidal purposes, nicotine extracts are scarcely ever prepared from duty-paid tobacco, but are obtainable as proprietary articles manufactured from refuse tobacco-stalks. At present, commercial nicotine is sold at a price which renders its use impracticable except for greenhouse use. By Section 4 of the Finance Act, 1912, duly licensed persons can be permitted by the Commissioners of Customs and Excise for the United Kingdom to grow tobacco for insecticidal purposes, that shall be free of duty. An article in the English Board of Agriculture Journal for March 1913, based largely upon experimental work at the South-Eastern Agricultural College, Wye, Kent, England, gives general information to persons desiring to avail themselves of this privilege. The most suitable varieties of tobacco for the purpose are the coarse-growing ones, such as *Nicotiana rustica*, but the nicotine content of the crop will depend largely upon climate, soil, manuring, and the system of cultivation. The heavy expense associated with the curing, grading, and packing of tobacco for smoking purposes is of course eliminated, and in hop gardens where an oast or drying kiln is usually available the expense of producing an insecticidal nicotine preparation will be small.

The leaves are broken up as finely as possible, after drying, and the nicotine content extracted by three successive soakings in water, 1 gallon to 1 lb. of leaves, each soaking lasting a day. Assuming the amount of nicotine in the leaves to be 3-4 per cent, 3 gallons of such extract plus 2 more gallons of water will give a wash with nicotine content 0·6-0·28, which is an effective strength against hop aphis, for example.

In France three varieties of nicotine are sold by the State: firstly, ordinary standard tobacco juice containing 1-2 per cent of nicotine; secondly, strong juice containing 4 per cent; thirdly, a standard nicotine extract containing 10 per cent. Such extracts are largely used against vine pests.

In America various proprietary extracts are in use. *Blackleaf*, and *Blackleaf* 40, are claimed to contain 2·7 per cent and 40 per cent respectively of nicotine sulphate. Blackleaf 40 is diluted usually at the rate of 1 part in 1000 of water. *Nico-fume*, another proprietary article, contains 40 per cent of free nicotine.

Nicotine sulphate is non-volatile, but if made up with soap solution free nicotine is liberated in the spray solution. If nicotine solution, say $2\frac{1}{2}$ quarts of 40 per cent solution, be mixed with $1\frac{3}{4}$ quarts of commercial oleic acid ("red oil"),

a solution of nicotine oleate is obtained which, being a soap solution and capable of emulsifying oils, is eminently adapted for spray purposes. Being, however, non-volatile, it should not be used upon food plants. Lime-nicotine sprays are used extensively in the United States. Thus a combination of 2½ U.S. gallons of lime sulphur, 50 lbs. hydrated lime, and 1 U.S. pint of nicotine sulphate to 100 U.S. gallons of water, used at a pressure of 300 lbs., is found to be very efficient against Psyllids, particularly against the Pear-Psyllid (*Psylla pyricola*).

In the British Isles nicotine is used with soap solution or with paraffin emulsion at a strength of 0·025-0·05. Thus half a pound of free nicotine per 100 gallons of 1 per cent soap solution is recommended by Petherbridge (1918) against Apple Capsids (*Plesiocoris rugicollis*), and half a pound of nicotine per 100 gallons of 2 per cent paraffin emulsion is recommended by Lees (1918) against sucking insects and caterpillars in general.

A considerable amount of experimental work has been carried out recently with nicotine with the aim of discovering a really efficient contact dust. Smith (1921) has tested a whole range of dusts containing from 1 to 75 per cent of nicotine against very many species of Aphides, Thrips, and caterpillars, and asserts that insects vary greatly in susceptibility to nicotine. The toxicity of the dust is influenced apparently by the nature and amount of nicotine used, and by the nature of the diluent. The nicotine seems to act as a fumigant so that it should be in as volatile a form as possible. The diluent should be fairly heavy, finely divided, dry, and non-absorbent. Kaolin is very suitable, calcium carbonate and sulphur slightly less so. Pure nicotine is the best form to use, but, as the percentage of it in the dust may have to be so high as 10, it is less expensive to use it in combination with some other insecticide; for example, Blackleaf 40, kerosene, and dry lime sulphur form a powerful dust.

Two great disadvantages of nicotine as a dust, according to the experience of Headlee (1922), are: (*a*) that rain falling within the first seventy-two hours seems to reduce, or even stop, its action; (*b*) the cost is greater than that of an equally effective spray solution. The great advantages of the dust are, on the other hand, the greater speed with which it can be applied, and the operator's independence of a water supply.

The action of nicotine in a dust seems to be slower than if in solution. The maximum efficiency of the dust seems to be reached within twenty-four to seventy-two hours after

application, whereas a spray solution reaches a high point of toxicity within the first two hours.

The physiological effect of nicotine upon the insect would appear to be one of paralysis of the motor centres, brought about by a condensation of the vapour upon the walls of the tracheae and subsequent absorption of the liquid by the tissues. As a stomach poison it is much slower and less effective.

**Quassiin** in the form of an extract of quassia chips has long been a popular specific against Aphides, the Hop Aphis in particular. The quassia is derived from either *Picrasma excelsa* (Jamaica quassia) or *Quassia amara* (Surinam quassia) by maceration in boiling water. The percentage of quassia in the chips varies, but should average 0·75.

Methods of preparing the insecticide are :

1. The boiling of 5 lbs. of chips in 50 gallons of water, allowing to infuse for twenty-four hours, decanting the extract and adding 50 gallons of 1 per cent soap solution.
2. To 5 gallons of 20 per cent soft-soap solution add an infusion of 2½ lbs. of quassia chips soaked for twelve hours in 5 gallons of boiling rain-water ; make up to 40 gallons.

*Quassiin*, the alkaloidal principle, is an amorphous or crystalline colourless and odourless solid, slightly soluble in water and more soluble in organic acids and alcohol. It is non-poisonous to higher animals.

The efficacy of quassiin as an insecticide would appear to be somewhat doubtful, in spite of its widespread popularity. MacIndoo and Sievers (1917) assert, after much experimental investigation, that quassiin cannot be relied upon against all species of Aphides ; and even where effective, the result is no greater than and just as expensive as if nicotine sulphate were used, and with the disadvantage of far slower action. In the British Isles, however, quassia insecticides are undoubtedly cheaper than nicotine preparations, but their value against all but a very few species of Aphididae would seem to be hardly worth the trouble of preparation.

**Pyrethrum** powder is the pulverised flower-heads of *Pyrethrum cineriae-folium*, *Chrysanthemum coccinereum*, *C. roequm*, and *C. carneum*, grown chiefly in the Mediterranean area, particularly in Montenegro, Dalmatia, Herzegovina, and Istria. At one time it was held that pyrethrum of insecticidal value could only be grown in these districts, but, as a matter of fact, really good pyrethrum can be grown in any warm,

dry area where the soil is poor, stony, and calcareous, and its cultivation is now being encouraged in Italy and Southern France. The substance is generally used as a dust, diluted with three or four times its weight of flour, fuller's-earth, or sulphur, but an aqueous extract can be obtained by macerating 6 lbs. of powder in 10 gallons of water for twenty-four hours. The extract is diluted for use with six to eight times its volume of water.

The usual formula for a pyrethrum soap solution is: $1\frac{1}{2}$ lb. pyrethrum powder, 2 lbs. soft soap, to 10 gallons of water. The powder, however, tends to clog the spraying nozzles.

Attempts are now being made to obtain an extract of the toxic principle, probably an oleo-resin, by using such solvents as ether, alcohol, or carbon tetrachloride, concentrating the extract, and adding the soap; such a stock solution should be diluted at the rate of 1 gallon to 9 of water.

Pyrethrum is a contact poison, and most larvae and soft-skinned insects are thrown into convulsions under its influence; but as it soon loses its effectiveness when it is exposed to the atmosphere, its practical use is somewhat limited to conservatory plants and as an insect powder, although in France it is now becoming extensively used against vine moths.

# CHAPTER VIII

## INSECTICIDES—*concluded*

### Organo-metallic Preparations

THE range of organo-metallic compounds which are potential insecticides is enormous, and it is quite possible that in the future their use may completely supplant the purely metallic and purely organic insecticides at present in use.

At present, however, there are few of such compounds that can be said to be in common use as insecticides, and of these few the vast majority are *soaps*, and to a much less extent *acetates* and *cyanides*.

A soap, chemically speaking, is a metallic salt of a fatty acid. Such a salt is obtained when a fat or oil, which is a glyceride of a fatty acid, is acted upon by a metallic oxide or hydroxide, the process being usually termed *saponification*. The physical properties of the soap will depend upon the nature of the metallic base. Thus the soaps of copper, iron, or lead are insoluble in water ; soaps of sodium or potassium are more or less soluble in water ; sodium soaps are firm and hard ; potassium soaps soft, viscous, or gelatinous. The soaps which are colloidally soluble in water—that is to say, the sodium and potassium soaps—are the only ones used insecticidally, and they may be divided into :

1. Hard, or laundry soaps, which are the sodium salts of palmitic, stearic, and oleic acids.
2. Soft, green, or black soaps, which are the potassium salts of various fatty acids ; thus whale-oil soap is, or should be, the potassium salt of dogleic acid, contained in whale oil, but the term is now merely a trade name for any potassium salt of a fish-oil fatty acid. Usually such soaps contain excess of alkali, and are therefore somewhat more insecticidal than are hard soaps.

Soaps are used, generally speaking:

(*a*) As direct contact poisons against soft-skinned insects. Thus 1 lb. of fish-oil soap to 6 gallons of water is useful against such Aphides as are not protected by waxy secretions.

(*b*) As emulsifiers of kerosene and cresol.

(*c*) As an addition to a wash to promote spreading power. It is generally useless, however, to add soap to washes which contain acids or organic salts, as the soap will be precipitated.

**Paraffin Compounds**

Crude mineral oil is a mixture of twenty or more chemical compounds differing greatly in composition and chemical properties from one another. With the exception of certain oils distilled from Scottish shales, the commercial crude petroleum is a mixture of the Paraffin series of hydrocarbons, and occurs as vast subterranean deposits in America, Russia, Rumania, Borneo, etc. It issues under pressure, or is pumped from wells, and is separated by fractional distillation into separate fractions of different boiling-points, some being gaseous, some liquid, some solid. The liquid portion, which is crude petroleum, consists, according to volatility, of three portions. Some 8-10 per cent consists of very volatile products with low boiling-points, known collectively as *petrol* or *gasoline* and separable into *petroleum ether* (B.P. 70-90 degrees C.), *petroleum naphtha* or *ligroin* (90-120 degrees C.), and *petroleum benzene* (120-150 degrees C.).

Some 70 per cent consists of compounds with boiling-points ranging between 150 and 300 degrees C., the *kerosene* or lighting-oil class.

Oils with a boiling-point above 300 degrees C. are generally classed as *lubricating oils* and *vaselines*.

Apart from the use of crude oil, to some extent, in America, insecticidal paraffins belong to the kerosene class, such substances of medium volatility being, as pointed out previously, more suitable for this kind of work than are substances of high volatility. Commercial kerosenes vary in physical and chemical characteristics, even when from the same oil-field, and may contain varying percentages of different paraffins.

American kerosenes of the *lighting-oil class* (Guelder Rose, White Rose, Royal Daylight) usually have initial boiling-points between 150 and 160 degrees C., and usually contain an 18-30 per cent fraction with B.P. under 200 degrees C., a 29-36 per cent fraction with B.P. under 250 degrees C., and a 33-60 per cent fraction with B.P. above 250 degrees C. In the *solar*

*distillate class*, initial B.P. 240 degrees C., 94 per cent of the oil has a boiling-point above 250 degrees C.

Now, according to Moore and Graham (1918), the greater toxicity of low boiling-point fractions to insects is counterbalanced by greater toxicity to plants, and any attempt to minimise this toxicity to plants, by emulsifying the oil, will minimise the toxicity to insects also. That is to say, in an emulsion a high B.P. fraction would be found more toxic to both insects and plants than would a low B.P. fraction.

Pickering (1906, 1908), as the result of trial with a whole series of kerosenes, crude oils, solar distillates, and motor spirits, used undiluted against Scale insect eggs, affirms that for an undiluted oil to be effective it must have at least a 40 per cent fraction with B.P. above 250 degrees C. Such a condition is satisfied by the best type of lighting oils and by solar distillates. The latter, being of low volatility, are of course more liable to injure the plant, but the injury is apparently slight upon dormant wood, and they are one-third the price of lighting oils. As regards the effect of these oils upon foliage, trials were made of series of oils ranging from petroleum ether to solar distillates; all produced scorching when used undiluted, and the lighter the oil the more quickly the scorching became apparent. Thus, with petrol, scorching appeared within five minutes, reached a maximum within seven hours, and remained at this for twenty-seven days, after which a gradual recovery occurred, the ultimate effect amounting to 37 per cent of leaves scorched. With solar distillate, scorching took five days to reach a maximum, but no recovery occurred, and the damage was 98 per cent. With oils of intermediate type, no scorching was apparent until four or five days after spraying, and never more than 30 per cent of the leaf area was affected.

The application of petroleum where foliage is not concerned is purely a mechanical one, but where plants are in question the concentration of oil used must be the minimum that will kill the parasite, so that injury to the plant may be eliminated or reduced. It is safer, therefore, to dilute the oil with water, either alone or in the form of an emulsion.

*Undiluted petroleum* is undoubtedly one of the most efficient anti-Scale insecticides that it is possible to use, but its use requires such great care and experience if serious injury to the plant is to be avoided, that it is gradually being abandoned.

Against Scale insects upon dormant trees, undiluted oil can be applied safely and effectively if the tree be dry, the oil at 60 degrees F., and an atomiser providing a good pressure made use of.

The main insecticidal use of undiluted petroleum, however, is as a mosquito larvicide, by spreading it as a thin film over the surface of accumulations of water infested with mosquito larvae. If pure kerosene be dropped upon water it collects into small areas and spreads very slowly, but an improvement in spreading power can be effected by the addition to the kerosene of 0·1 per cent of asphalt varnish. In crude oil, asphalt-like impurities occur normally, so that its spreading power is superior to that of kerosene. Owing, however, to variations in the density and spreading power of different samples of crude oil, no rule can be laid down as to the amount of oil per unit area. The film need only be very thin, but must be continuous, and great difficulty is found in ensuring this.

An oil film is best produced by spraying, but for the production of a continuous film some other method is necessary. For example, oil drips, *i.e.* a can of kerosene with a drip tap attachment, may be used over drains. For streams, an oil bubbler can be used, made from a can of 2-3 gallon capacity, into the top of which two spigots are fitted, one as an oil outlet, one as a water inlet. The spigot serving as a water inlet has a one-inch diameter pipe attached and extending almost down to the bottom of the can. The difference between the weight of the column of water in this pipe and a column of oil of equal length causes the oil to come off in bubbles. Such a bubbler will last two or three weeks without renewal.

Another method is: to suspend a petroleum-filled petrol-can from a stake and provide it with a wick of six-ply jute binder twine, one end fastened in the can, the other end in the water. To retard the flow of oil, the stream is obstructed by a float which is an inch-square stick held in place by two stakes inclined down stream so as to permit rise and fall.

For rapid oiling of water-filled cart-tracks and hoof-prints, sawdust that has soaked for twenty-four hours in crude oil may be distributed by hand.

The exact toxic effect of petroleum upon mosquito larvae is disputed. It has been asserted, at various times, that the larvae are suffocated; that the alteration of surface tension renders them unable to hang to the surface film, so that they drown; that they are poisoned by oil dissolved in the water; that their spiracles and tracheae become blocked; that the vapour is the lethal agent. According to Freeborn and Atsatt (1918), oil does not annul the surface tension between the larvae and the water surface, and they remain at the surface some time; larvae kept from air by mechanical means lived for thirty hours, but under a layer of kerosene died in forty-five minutes; blocking of the tracheae is not a sufficient reason,

since kerosene kills in forty-five minutes and a non-toxic liquid petroleum required four and a half hours; actual action of the oil upon the tissues is not a sufficient reason, as larvae die before the oil penetrates to the tissues. The conclusion arrived at by these observers was that the oil vapour is the lethal agent, and that the toxicity of petroleum as a larvicide increases with the volatility.

A Japanese observer, Takatsuki (1917), has shown that the surface of the respiratory organs and siphons of mosquito larvae is covered with epithelium, which, whilst not stained by water-soluble dyes, is intensely coloured by Sudan III. suspended in petroleum; he suggests that this epithelium has a special affinity for petroleum, and calculates that only 26 c.c. of oil is required per square metre of water surface, and that an oil emulsion is better than crude oil alone.

*Diluted petroleum* generally takes the form of a mechanical mixture of minute globules of kerosene suspended in water, the solubility in water being very slight; the kerosene content is generally about 15 per cent. Such a mixture is very unstable, requires constant agitation, and, although machines for spraying this mixture have been put upon the American market, the difficulty of adjusting and maintaining the proportion of oil to water has kept them out of popular favour; the use of such mixtures is giving way everywhere to that of emulsions or of miscible oils.

*Emulsions* of paraffin in water have been used for a considerable time as insecticides, and there is a huge variety of recipes, good, bad, and indifferent, for such emulsions.

When ordinary kerosene is churned up with water, the milky liquid is extremely unstable. If, however, the interfacial tension between the two liquids be modified by the addition of emulsifying agents, the emulsified mixture can remain stable for some considerable time, owing to the reasons which have been already discussed.

The agent must be colloidally soluble in the dispersing fluid. Soap, colloidally soluble in water, is the usual emulsifier in petroleum emulsions, but iron hydroxide, basic sulphates of iron and copper, soluble silica, zinc sulphide, gelatine, all give excellent emulsions. The agent forms a layer around the oil drops and prevents them coalescing, although how that is exactly effected is still doubtful.

If soft soap be the emulsifying agent, the general principle in emulsion recipes is to limit it to less than 3 per cent of the total weight of diluted emulsion, and to allow at least two parts of kerosene to one of water in the stock solution. If the amount of oil in the stock be less than 67 per cent, the

emulsion is unstable; if in excess of 67 per cent, the emulsion is gelatinous. An emulsion containing 98 per cent of oil can be cut with a knife. Commercial oil emulsions generally contain about 85 per cent of paraffins, and may contain in addition about 4 per cent of cresylic acid. Such emulsions, though as a rule very effective, at the recommended dilution of 1 gallon to 9 of water, are considerably more expensive than home-made preparations.

Formulae for oil emulsions vary greatly.

The *Hubbard-Riley formula*, very popular in America, allows 2 gallons of kerosene and ½ lb. of hard soap to 1 gallon of water; this stock solution is diluted at the rate of 1 gallon per 9-30 of water for use.

The *Kruger formula*, employed in Germany against Psyllids and Aphides, allows equal parts of each constituent by weight, namely 10 gallons of water, 100 lbs. of soft soap, and 10 gallons of kerosene; it is diluted at the rate of 1 gallon of stock per 10-20 of water.

*Delacroix's formula*, used in France, stipulates 10 gallons of water, 1 gallon of petroleum, 20 lbs. of soft soap, 10 lbs. of sodium carbonate, diluted as in the formulae given above.

*Cook's formula* gives 10 gallons of water, 25 gallons petroleum, 50 gallons soft soap, diluted as above.

Whatever the formula adopted, however, the general method of preparation is always the same. The emulsifier is first added to the water and the oil then added gradually. This order of things is necessary in order that the emulsion may contain the oil in the form of drops. The smaller and more uniform the drops, the more stable the emulsion, the more spreading power it will possess, the greater the security to the plant. Mere stirring of the liquid is useless. It must be churned up through a syringe with a rose jet. The temperature of the water need not be high, but a high temperature certainly facilitates emulsification.

As regards the liability of kerosene emulsions to scorch foliage, the damage is inappreciable so long as the percentage of oil in the spraying solution does not exceed 2 per cent. On dormant trees, a solution containing 6 to 36 per cent of kerosene may be used with impunity, particularly if precautions are taken to rechurn thoroughly the emulsion both before and after dilution.

Emulsions containing crude oil cannot be used upon foliage, but are very effective as winter washes upon dormant trees; even thus, it is not advisable to use them unless a spraying pressure of at least 200 lbs. is available.

*Miscible oils* are soapy liquids, produced by the addition

of vegetable oils to petroleum, and readily miscible with water to form a milky-white fluid. The diluted spraying solution is thus considerably more convenient to prepare than a kerosene emulsion, and both in America and Great Britain several proprietary brands can be found on the market. Their preparation, however, is not a matter of great difficulty, the following methods being typical:

FORMULA A.—Emulsifier, 9 gallons ; kerosene, 40 gallons ; resin oil, 6 gallons ; water, as required, about 1¼ gallon.

The emulsifier is prepared by boiling fish oil (10 gallons), crude carbolic acid (8 gallons), caustic potash (15 lbs.) together in a covered iron vessel until a temperature of 300 degrees F. is reached. Then the liquid is transferred whilst still hot to a barrel, and 14 gallons of kerosene are added; after the kerosene is stirred in, 22 gallons of water are added.

FORMULA B, the Connecticut formula.—Emulsifier, 8 parts ; crude petroleum, 18 parts ; resin oil, 4 parts ; water, 1 part.

The emulsifier is prepared by heating together crude carbolic acid (2 quarts), whale oil (2½ quarts), and caustic potash (1 lb.) to a temperature of 300 degrees F. The liquid is removed from the fire, 3½ quarts of kerosene added, and then 5½ quarts of water (Smith, 1908).

Such miscible oils are diluted at a rate not greater than 1 part to 15 of water, and are used on dormant trees only.

### Sulphur Compounds

The world's supply of raw sulphur comes chiefly from Sicily and from Louisiana. It is obtainable commercially as *ground sulphur*, as *sublimated* or "flowers of sulphur," as *precipitated sulphur* ("milk of sulphur"), or as *wind-blown sulphur*. The insecticidal value is proportional directly to the purity and fineness.

Precipitated sulphur is the finest. It is usually a by-product of coal-gas purification, and as it contains tar and cyanides it is apt to scorch plants; if prepared chemically by the precipitation of polysulphide solutions with acids, the product is dearer but more valuable from an insecticidal standpoint, since the alkaline sulphides present as impurities have possibly a greater toxic action upon insects than sulphur itself has.

The use of sulphur by itself as an insecticide is somewhat limited. It is frequently recommended as a diluent or carrier for other chemicals in the preparation of repellent or fungicidal

dusts. It is useful as a dust, undiluted, against Red Spider, and seems really toxic and not merely repellent; but whether the toxic action is due to sulphur vapour or to the formation of sulphuric acid, or even sulphuretted hydrogen, is not very certain.

There are several disadvantages attendant upon the employment of sulphur dusts: in particular, there is a great wastage of material if any wind be present; there is also considerable risk to the eyes of the operator. On the other hand, the aversion of sulphur to water renders the use of an aqueous suspension somewhat difficult. To counteract this aversion various substances have been recommended: soap, flour paste, oleic acid, glue, dextrin, diatomaceous earth, etc. For example, 2 oz. of powdered glue are dissolved in 3 gallons of hot water, 10 lbs. of sublimated sulphur are added and stirred up to a smooth paste. The paste should be strained through a fine sieve and diluted to 200 gallons.

### Lime Sulphur

The value of the alkaline sulphides and polysulphides as insecticides is now a matter of common knowledge, owing to the extensive use of *lime sulphur wash* as a spraying fluid for plants. Formerly known only as a sheep dip, this preparation of the polysulphides of calcium is probably now the most important contact poison in common use.

Its possibilities, so far as the British Isles are concerned, have been summed up by Theobald (1914). It is inferior to caustic soda or lime-salt solution as a winter tree-cleanser, and with old trees has no value at all; it would seem to have little or no effect upon insect eggs; as a summer insecticide it is definitely useful against Pear-leaf Blister Mite (*Eriophyes ribis*), Peach Scale (*Eulecanium persicae*), Pear-tree Oyster Scale (*Aspidiotus ostraeformis*), and San José Scale (*Aspidiotus perniciosus*), and also under certain conditions against newly hatched Mussel Scale (*Lepidosaphes ulmi*) and some species of Red Spider (*Tetranychus*). It has some slight value as a stomach poison for some caterpillars.

When milk of lime and sulphur react, under commercial conditions of manufacture, the resulting products are the *sulphite* and *thiosulphate of calcium*, and the *tetrasulphide and pentasulphide of calcium*, all except the first named being soluble in water.

Of these compounds, neither the sulphite nor the thiosulphate seems of value from an insecticidal standpoint, whereas the polysulphides are undoubtedly of great use, their strong

affinity for oxygen restricting the supply for the insect and so bringing about its death (Tartar, 1914; Vermorel and Dantony, 1919).

In the preparation of this mixture, the ratio of lime to sulphur should be theoretically as 1 : 2; but as in practice the amount of calcium oxide in commercial lime rarely exceeds 95 per cent, a little more lime than the theoretical formula indicates is desirable. The maximum amount of sulphur per 100 c.c. of water which can be converted is 18·4 grams—that is to say, a ratio roughly of sulphur to water of 1 : 5, so that two parts of sulphur will require ten parts of water, and the formula will be 1 : 2 : 10 of lime, sulphur, water.

This is the formula generally recommended. The best commercial quicklime, with not more than 5 per cent magnesium oxide impurity, must be used. Air-slaked lime is of no use. The lime should be freshly burned, not more than two or three days old, and in medium-sized pieces. Iron boilers must be used, as the mixture attacks copper.

One-fourth of the water to be used is placed in the boiler and heated. When tepid, the lime is gradually added. There should be one gallon of water in the boiler for each pound of lime to be added. No stirring should be done. When the lime-water begins to boil, the sulphur is added through a sieve held over the boiler, and the mixture is now continuously stirred and boiled until it becomes yellowish-white in colour. The rest of the water is then added and the boiling and stirring continued for an hour. The preparation is then strained. The solution should be a deep red in colour, and should give a reading of 29-30 degrees on the Beaumé hydrometer (Savastano, 1914). Such a solution should be diluted at the rate of one gallon to thirty of water (1 degree Beaumé) for summer use, and at the rate of one gallon to seven of water ($3\frac{1}{2}$ degrees Beaumé) for winter use.

To avoid the trouble and expense of boiling, several formulae can be made use of which, by allowing excess of lime or by inclusion of caustic soda as an ingredient, utilise the heat of chemical reaction. Smith (1908) recommends the following: 40 lbs. lime, 20 lbs. sulphur, 50 gallons water; the lime and the sulphur are mixed; sufficient water to induce a brisk slaking is added; the vessel is covered with a blanket to avoid loss of heat; water is added as needed for the continuation of the slaking; and the mixture is stirred occasionally. This process is kept up till all the lime is fully reduced. The mixture is allowed to stand for an hour, is diluted with warm water and used at once. Or the following formula can be made use of: 33 lbs. lime, 17 lbs. sulphur, $4\frac{1}{2}$ lbs. caustic soda, 50 gals. water.

Two-thirds of the lime is slaked thoroughly with hot water, and during the process one-half of the sulphur is sifted in. The remainder of the lime and hot water is added, and whilst the boiling continues the rest of the sulphur is added, and water as needed. Whilst yet steaming, add one-third of the soda, which will cause a violent boiling; before this subsides, add another third, and then the final third. Keep stirring and adding hot water until the brick-red colour of the solution indicates that the full combination of lime and sulphur has occurred. Then dilute to 50 gallons.

The objections to self-boiled lime-sulphur are twofold:

In the first place, the excess of lime causes the wash to be thick and to lack spreading power; great pressure is required to force it through the spraying nozzles. Secondly, there is a risk of the reaction between the lime and the sulphur being incomplete, the heat of the slaking being liable to vary according to the freshness of the lime, the temperature of the water used, and the total bulk of the substance required.

One of the drawbacks to the use of lime-sulphur has always been its bulkiness and the difficulty of storing it. It is difficult to prepare as a powder, and although so-called "dry lime-sulphur" has now been placed upon the market there is some variance of opinion as to its efficacy.

On the other hand, the corresponding polysulphides of sodium, potassium, and barium are more stable, and can be obtained as dry powders. As the actual metallic constituent of a polysulphide wash would seem to be immaterial so long as the wash has a sufficient polysulphide content, there is undoubtedly a future for such dry polysulphides if cheapness and ease of manufacture can be attained.

*Barium polysulphides*, for example, are as good as the calcium salts, particularly in respect to foliage injury and economy of cost. Barium sulphide if boiled with excess of sulphur in water is converted into the *pentasulphide*. This, when dry, breaks up into the *tetrasulphide* and free sulphur. The tetrasulphide is readily soluble in cold water, and is quite as effective as lime-sulphur when used at a strength of 10 to 32 lbs. per 40 gallons of water (Scott, 1915).

*Sodium sulphide* has been employed to some extent as a dormant spray, being sold commercially as a powder termed *soluble sulphur*, or as a liquid under the name of *sulphocide*. It can be prepared by adding 1 lb. of strong caustic soda and 1½ lb. of sulphur to half a gallon of hot water; the heat of reaction brings about combination in a few minutes. The solution is diluted to eight times its volume.

*Potassium sulphide* has been used with considerable success

in Italy against Scale insects as a 5-7 per cent solution. The addition of 1 or 2 per cent of rye-flour paste improves the rate of toxicity. The substance is very hygroscopic, however, and its success is less marked in a humid atmosphere.

### Tar Compounds

*Crude tar* is a collective term comprising a number of compounds derived from the destructive distillation of wood or coal. Distillation of wood yields *wood tar*, which is a mixture of phenols, cresols, phlorol, guiacol, and creosote.

*Coal tar*, a by-product of the dry distillation of coal, is a black, viscid substance, a mixture of some fifty organic compounds. By fractional distillation there can be separated :

1. *Light oil* or crude naphtha, which distils up to 150 degrees, and contains *benzene*, *toluene*, and *xylene*. It constitutes 3-5 per cent.
2. *Middle oil* or carbolic oil, which distils from 150 to 210 degrees, and contains *naphthalene* and *carbolic acid*. It constitutes 8-10 per cent.
3. *Heavy oil* or creosote oil, which distils from 210 to 270 degrees, and constitutes 8-10 per cent.
4. *Anthracene oil*, distilling from 270 to 400 degrees, and containing *anthracene*. It is coloured green, and forms 16-20 per cent. *Pitch* remains in the still.

Middle and heavy oils constitute commercially *crude phenols*, the class of tar compounds chiefly used in insecticidal work. Great confusion exists as to the nomenclature of these commercial phenols ; often no apparent distinction exists between products sold as crude carbolic acid, creosote oil, and coal-tar creosote. According to Gray (1916), "crude carbolic acid" and "creosote oil" are synonymous terms for the mixed residues from tar refineries, and contain variable amounts of phenols. True phenol or carbolic acid (*hydroxybenzene*, $C_6H_5 . OH$) is not present, or present at most as a mere trace. The bulk of the oil consists of cresylic acid (*hydroxytoluene*, ($CH_3 . C_6H_4 . OH$) and higher phenols, and would be better termed "crude cresylic acid."

The application of crude phenols to insecticidal work has been limited chiefly to the production of soil fumigants, repellents, animal dips and dressings, antiseptics, and insecticidal soaps. Their variable composition (the amount of total phenols varying from 5 to 40 per cent), their causticity, and the difficulty of diluting them with water, have mitigated against their use as foliage sprays. Still, they are used to

some extent in the preparation of miscible oils and in the form of emulsions. An emulsion consisting of water 33½ gallons, whale-oil soap 40 lbs., crude carbolic acid 4 gallons, diluted at the rate of one gallon to twenty of water, has been found successful in penetrating the waxy outer covering of Mealy Bugs (*Pseudococcus*) in California.

In Germany, phenolic preparations, chiefly crude wood tar or coal-tar creosote, are being used for insecticidal purposes under the name of *carbolineum*. Soluble carbolineum is prepared commercially in many forms and under different names, and these commercial products differ widely in chemical and physical characters, some being injurious to plants.

Mixtures of crude phenols with vegetable oils or soaps yield a class of substances known as *lysols*, *sapocarbols*, and *creolins*, liquid brownish oils, transparent and soluble in water. They have good wetting powers and are very toxic to insects, 1 per cent solution killing Woolly Aphides, for example; but even very dilute solutions are apt to injure foliage.

*Cresol*, which constitutes the bulk of the phenolic constituents of crude phenols, differs from pure phenol (carbolic acid) in being liquid at ordinary temperatures, whereas carbolic acid, if pure, exists at ordinary temperatures in the form of needle-shaped crystals generally pinkish in colour.

Commercial cresol is generally a mixture of *ortho-*, *meta-*, and *para-cresol*, their separation being difficult. It is rarely used pure, but is generally saponified. *Lysol*, for example, is a mixture of crude cresol with linseed or rape oil, and saponified with potash.

*Antinonnine*, a powerful insecticide employed in Germany against the Nun-Moth Caterpillar (*Liparis monacha*), is said to be a mixture of equal parts of potassium dinitrocresylate and soap.

**Naphthalene**, the hydrocarbon which is present in coal tar in the largest quantity, comes over in the second fraction, distilling between 170 and 230 degrees, and on cooling appears in the form of crystals separable from the phenols, etc., by pressure.

It is a colourless solid, crystallising in shining plates which have a characteristic smell and are extremely volatile.

Naphthalene has apparently no toxic action upon insects unless combined with paraffin, but has a repellent effect.

In the West Indies, two preparations termed *paranaph* and *scalo* have been used with great success against fleas, ticks, Scale insects, and Aphides. In principle they consist of a saturated solution of naphthalene in paraffin jelly. For example, 56 lbs. of best soft soap are dissolved in 2 gallons

of boiling water, 6 lbs. of naphthalene are added, and the mixture stirred until the latter substance is dissolved. The mixture is removed from the fire, and churned up with 2 gallons of paraffin. The result is a semi-solid substance readily soluble in water.

According to the recipe of Lefroy, 2 lbs. of whale-oil soap are heated to boiling-point and 4 oz. of naphthalene are dissolved in it. Then $5\frac{1}{2}$ pints of crude petroleum are stirred in.

*Scalo* results from a modification of the above two recipes: 5 lbs. of whale-oil soap are dissolved in 2 gallons of hot water, 6 lbs. of crude naphthalene added, and when the mixture is boiling vigorously it is removed from the fire and to it are added 4-5 gallons of paraffin; then it is reheated, and another 4 gallons added. The resulting product is very effective against resistant species of Scale insects, if used at the rate of 1 lb. per gallon of water.

**Pyridine,** another coal-tar product, has been used as a contact poison against larvae of the French Vine Moth (*Polychrosis botrana*), but the wash only retains its toxic character for two days after application. The formula used is: pyridine, 2 oz.; soap, $1\frac{1}{2}$ oz.; water, 100 oz.

Pyridine oleate is said to have more wetting power and to retain its toxic efficiency longer.

### Combination Insecticides

The obvious economy of time and labour derivable from the use of an insecticide that would be effective against both biting and sucking insects, or against insects and fungi, has led to many attempts at the production of such a substance, but as yet it has not been found possible to devise anything better than a mere mixture of stomach and contact poisons, or of insecticide and fungicide. Many such mixtures have been put forward, and the chart (Fig. 8) is based upon the suggestions of many authorities. It must be pointed out, however, that a desirable combination wash is not obtained merely by taking an acknowledged stomach poison and an effective contact poison or a fungicide, and mixing them in such proportions as will not lead to plant injury; other factors enter into the question.

There may be chemical or physical incompatibility which will prevent the two from mixing; or chemical interaction may occur, the results of which may be actually injurious to the plant, or at best may lead to a lesser toxic efficiency than is possessed by each wash separately.

Gray (1914), who has investigated the question, puts forward the following tentative conclusions :

Better results by mixing : Paris Green with Bordeaux Mixture and iron sulphide. Lead arsenate with the same. Zinc arsenite with iron sulphide. Soap and Bordeaux Mixture. Nicotine and oil emulsions.

Properties unchanged by mixing : Calcium arsenite with Bordeaux Mixture, iron sulphide, or nicotine. Lead arsenate

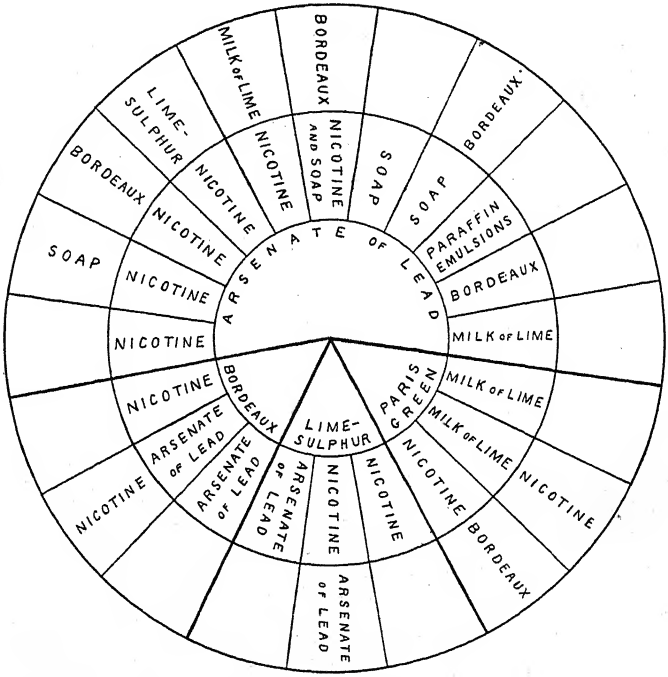



FIG. 8.—Chart showing spray materials which may be used together.

(acid) with nicotine. Lead arsenate (neutral) with Bordeaux Mixture, iron sulphide, nicotine, soaps, oil emulsions, and alkalies. Zinc arsenite with nicotine. Lime sulphur with cyanide fumigation or nicotine. Soap with nicotine, oil emulsions, or alkalies. Nicotine with cyanide fumigation and acids.

Efficient, non-injurious : Lead arsenate (neutral) with lime-sulphur, soap, and Bordeaux Mixture, nicotine and alkalies, Bordeaux Mixture and alkalies.

Inefficient, non-injurious : Neutral lead arsenate with acids.

Lime-sulphur with soap, alkalies, or acids. Emulsions with iron sulphide. Nicotine with Bordeaux Mixture, acids, and alkalies.

Dangerous: Paris Green with lime-sulphur, cyanide fumigation, soaps, emulsions, alkalies, and acids. Calcium arsenite with lime-sulphur and the same. Lead arsenate (acid) with soaps, emulsions, or alkalies. Zinc arsenite with lime-sulphur, soaps, emulsions, alkalies, and acids. Lead arsenate (neutral) with acids. Emulsions with lime-sulphur, alkalies, and acids. Cyanide fumigation and Bordeaux Mixture. Bordeaux Mixture with acids, or iron sulphide. Alkalies and iron sulphide.

# CHAPTER IX

## DIPS AND DRESSINGS

INSECTICIDES applied to animals for the purpose of mitigating or preventing the attacks of blood-sucking and disease-producing ectoparasites may be in the form of *hand-dressings* or *powders*, or of *liquid dips*. Their effect upon the parasite may be toxic or merely repellent. In this chapter, only such dressings as actually kill the parasitic organism will be dealt with, the question of repellent substances, so-called "insectifuges," being discussed in the chapter following.

An ideal insecticide for application to animals should obviously not only possess the necessary qualities of toxic efficiency and cheapness, but should be easy to apply, should be non-poisonous to the animal, without injurious effect upon the hide or wool, and should remain effective for some time after application.

*Hand-dressings* are usually difficult to apply, generally necessitate shaving the hair from the affected area, and are somewhat uncertain in their action. They have been superseded almost entirely by liquid-dipping preparations, except in cases where the area of infestation on the animal is localised, as in such diseases as parasitic mange or ringworm.

The toxic ingredient of such dressings varies enormously in various recipes, the most commonly occurring substances being *arsenious sulphide, free sulphur, cresols, pyridine* and its derivatives, *nicotine, mercury*, and *paraffin compounds*. These are applied generally in the form of ointments or smears—that is to say, made up with some kind of fat or with Stockholm tar; but sometimes they are in the form of an emulsion or of an aqueous solution.

Some typical recipes may now be appended.

Firstly, against Sucking Lice (*Pediculidae*).

The investigation of practicable pediculicides has been enormously stimulated by the conditions existing in the armies of all the combatant nations during the Great War,

and only the barest summary of results achieved can be given.

Castellani and Jackson (1915), as a result of experimental work in Serbia, give the following pediculicides in order of efficiency: paraffin (kerosene), vaseline, guiacol, anise preparations, iodoform cyllin and similar preparations, carbolic acid solution, naphthalene, and camphor.

Pyrethrum would seem to have a very feeble action on Sucking Lice, and boric acid, corrosive sublimate, precipitated sulphur, and zinc sulphate, all in powder form, have apparently no action whatever.

According to Kinloch (1915), petrol is the most effective of the paraffins, lice and their eggs being destroyed by immersion in petrol for one minute or by exposure to the vapour for half an hour. Other fat-solvents, other than paraffins, such as benzene, toluene, and acetone, are as toxic to lice as is petrol. The most lethal substances of all, however, appear to be certain chlorine derivatives of methane, ethane, and ethylene, immersion of lice or their eggs in these substances being immediately fatal, and exposure to the vapour for five minutes being equally effective. The application of such substances is best effected in the form of ointment; for example, a 25 per cent solution of petrol or of trichlorethylene in vaseline. Infected garments would have to be steeped for thirty minutes at 12 degrees C. in an aqueous solution of soap containing 10 per cent tetrachlorethane or 2 per cent trichlorethylene. A 5 per cent solution of cyllin in water is equally effective, if a temperature of 65 degrees C. can be maintained.

According to this author, the common phenolic disinfectants have no destructive action on lice whatever at ordinary dilution and temperature, but are effective at 65 degrees C. Such volatile oils as wintergreen, cloves, turpentine, eucalyptus, thyme, etc., and such solid substances as iodoform, camphor, paraform, sulphur, borax, hellebore, and alum, are not directly fatal to lice, nor are hungry lice deterred from feeding by such substances, nor even by ointments containing mercury oleate or balsam of Peru.

Cresol soap solution, however (Jeyes' Fluid 1 oz., soft soap 24 oz., water 10 gallons), is recommended by several other workers; and although undoubtedly lice can close their spiracles against such a solution for short periods, soaking of garments for thirty minutes would seem to be fatal to any lice in them.

Peacock (1916), as a result of experiments with a wide range of insecticides and deterrents against lice, reports the most effective dressing to be a mixture of naphthalene 96 per

cent, creosote 2 per cent, and iodoform 2 per cent, and the efficacy of this formula is admitted by Kinloch, who, however, regards the iodoform constituent as useful only in rendering the mixture adhesive, and so replaceable, with saving of expense, by magnesium silicate. One drawback to this so-called N.C.I. mixture is that its moistness, unavoidable owing to the creosote ingredient, prevents its use in perforated tins.

A powder said to be six times as effective as the N.C.I. mixture consists of 20 grams of talc, 1 c.c. creosote, 5 grams sulphur; it is a dry powder, easy to apply, and non-irritant.

Anisol (methylphenyl ether) has been recommended by Kränkel (1915), but during the War was tried and discarded by the Australian military authorities in favour of inert powders impregnated with cyclohexanone or with cyclohexanone and cyclohexanol (Wesenberg, 1915).

According to Moore (1918), pediculicides with boiling-points below 265 degrees C. are the more toxic, but those with boiling-point between 300 degrees C. and 350 degrees C. have more lasting qualities. Heliotropine, 1 grain to 3 grains of cocoa butter (in ethereal solution) per forty-eight square inches of material, remained effective upon underwear for seven days.

*Biting lice* upon birds and mammals are generally more amenable to dusting or dipping methods than to hand-dressings, but Prussian Army Instructions during the War, for combating such lice on horses, include the following dressings:

(1) Grey mercuric ointment, not more than 150 grams at each application, brushed over the whole body with a horse-brush.
(2) Aqueous infusion of tobacco, one part in twenty-five of water.
(3) A mixture of one part petroleum to ten parts methylated spirit, or equal parts of petroleum and rapeseed oil.
(4) 2-3 per cent aqueous solution of creolin, or a 3 per cent solution of liquor kresoli saponatus.

Success with these dressings depends upon repeated applications at five-day intervals.

Lamson (1917) recommends mercuric ointment for obstinate cases of lice on poultry; the ointment contains 50 per cent metallic mercury with 50 per cent petroleum jelly, is diluted with two parts of vaseline, and rubbed well into the base of the feathers.

In cases of sarcoptic or of demodectic mange, hand-dressing is undoubtedly the only successful method of treatment, owing

to the necessity for the insecticide to be well rubbed into the skin, although during the War, in the British Army, dipping in lime-sulphur gave good results with horses infected with demodectic mange. In the German Army, which appears to have suffered severely from mange infection of horses, the official remedy was an application of a mixture of limewater and petroleum rubbed well into the affected area, which was previously shaved. This preparation is made by slaking 2 lbs. of fresh lime with cold or hot water and then adding 3 gallons of water. When the lime has settled, the liquor is decanted, diluted to 6 gallons, and mixed with 6 gallons of petroleum.

Human cases of horse-mange were completely cured in two to four days by daily application of petroleum rubbed in until the skin was dry, or by an ointment composed of 17 per cent sulphur and 8 per cent potassium carbonate in a basis of fat, or lanoline (Weidner, 1917).

The following is a French remedy against demodectic mange: titrated nicotine extract 1 lb., commercial soda crystals $1\frac{3}{5}$ oz., water 2 gallons (René, 1916).

For sarcoptic mange an oily dressing penetrates better; such as:

| | | |
|---|---|---|
| (1) | Kerosene | 2 parts. |
| | Linseed oil | 1 part. |
| | Soap solution | 2 parts. |
| (2) | Creosote | 1 part. |
| | Linseed oil | 20 parts. |
| | Soap solution | 30 parts. |
| (3) | Creosote | $\frac{1}{2}$ oz. |
| | Methylated spirit | 5 oz. |
| (4) | Carbolic acid | $\frac{1}{2}$ oz. |
| | Oil of turpentine | 1 oz. |
| | Oil of tar | $1\frac{1}{2}$ oz. |
| | Sulphur | 2 oz. |
| | Linseed oil | 1 pint. |

### Powder Dressings

The use of powder against animal parasites is in practice almost entirely limited to the treatment of domesticated birds or pet animals, and even with these there is an increasing tendency to consider powders and dust-baths as ineffective in controlling lice. There is considerable wastage due to powder being shaken out of the feathers, and most powders soon lose their efficiency.

Commonly occurring constituents of such powders are *cresol, sulphur,* and *sodium fluoride.* Thus a 3 per cent cresol

powder is recommended against fleas, and a mixture of cresol 4 oz., plaster of Paris 68 oz., gasoline half a pint, is effective against fowl-lice. Sodium fluoride (1 oz. to 5 oz. of flour) is recommended for lice on birds and mammals (Bishopp and Wood, 1917).

One ounce of powder suffices for a dog, 6 oz. for a yearling, applied preferably with a powder gun.

A formula against similar pests, issued by the Texas State Farmers' Institute, is: 1 pint of 2 per cent chlorine water mixed with half a pint of gasoline, and as much air-slaked lime added as the mixture will saturate.

### Dipping Fluids

In the treatment of large numbers of cattle or sheep against ticks and sheep-keds, scabies and sheep-scab, such a vast saving of time and labour is obtainable by swimming the animals through tanks containing fluid dressings, that the use of ointment or of powders has almost everywhere died out. Even for the treatment of small animals, dogs or cats for example, immersion in a warm 3 per cent solution of potassium sulphide or a 2 per cent solution of creolin is far preferable to the use of ointments or powders. Poultry, too, can be more effectively treated against Mallophaga by immersion in a half per cent solution of sodium fluoride plus the addition of an ounce of soap to each gallon, than by the use of the same substance as a powder. Dipping fluids, as used for horses, cattle, or sheep, whether proprietary articles or home-made preparations, may be divided into three classes: *arsenical*, *carbolic*, and *sulphur dips*.

### Arsenical Dips

The value of dipping fluids containing an arsenical ingredient is indisputable. Such dips are highly poisonous to ticks and mange-mites, are easily prepared, and remain effective for a considerable time after application. Arsenic enters into the composition of the majority of proprietary dips, and is the main ingredient of one of the oldest of such dips on the market.

When applied to *cattle*, arsenical dips, have few drawbacks, the chief disadvantage, namely the tendency to "scalding" or skin-injury, being quite easily avoided by emulsification of the arsenical ingredient, and by proper regard to the weather conditions at the time of application. On the other hand, however, the disadvantages attending the application of such dips to *sheep* are sufficiently serious to merit close attention.

In the first place, there is undoubtedly a tendency towards wool-injury, shown chiefly by a desiccation of the fibres and a weakening of them near the roots. Sometimes the skin of the animal becomes blistered and excoriated, and there is consequent absorption of arsenic through the broken surface, sufficient sometimes to kill the animal.

Secondly, the risk of pasture-poisoning by surplus dip dripping from the fleece or washed out by rain is by no means negligible. Speaking generally, therefore, whilst in Great Britain proprietary arsenical dips are still largely used by sheep-rearers, in Australia, South Africa, and United States they are becoming replaced in popular favour by other types of dipping fluid, notably by home-made sulphur dips.

An arsenical fluid, unlike an arsenical stomach poison, contains its arsenic in a soluble form, *sodium arsenite* being made use of almost invariably.

Now a cattle-tick is very resistant and requires a somewhat strong solution of sodium arsenite to kill it; in fact, the margin of safety between the toxic efficiency of the fluid and the possibility of injury to cattle is narrow. Exact control of the strength of the solution is therefore of the utmost importance, and close attention has to be paid to (1) the purity and strength of the chemicals used, and (2) the maintenance of the strength of the solution.

Commercial sodium arsenite should have an arsenic content equivalent to 80 per cent of arsenious oxide, but in practice the amount varies between 50 and 82 per cent, the variation being due to the fact that the substance is really a mixture of the *orthoarsenite* ($NaH_2,AsO_3$), the *pyroarsenite* ($Na_4,As_2O_5$), and the *metarsenite* ($NaAsO_2$) in varying proportions.

Owing to the variable composition of commercial sodium arsenite, therefore, it is preferable to prepare the dipping fluid by the interaction of arsenious oxide and sodium carbonate or caustic soda, and such a method is adopted in Australian and American recipes.

Thus, for example, Ellenberger and Chapin (1919) give the following recipe for the preparation of an arsenical dip: 4 lbs. of caustic soda is dissolved in 1 U.S. gallon of water, and to this solution is added 10 lbs. of white arsenic in portions of 1 lb. or 2 lbs. at a time. The liquid must be continually stirred, unless owing to the heat of reaction it begins to boil, in which case it must be allowed to cool before any more arsenic is added. If the liquid remains muddy or milky, another gallon of water must be added; and if it does not clear then, it must be heated nearly to boiling-point so as to dissolve the arsenic. The solution is diluted to 4 U.S. gallons and 10 lbs. of washing-soda

crystals added and allowed to dissolve. When cold, the solution is made up to 5 U.S. gallons. To this stock arsenical solution, when about to be used, a U.S. gallon of pine tar mixed with $\frac{3}{4}$ lb. of caustic soda dissolved in 1 quart of water is added, and the whole well stirred. One U.S. gallon of the resulting dip is diluted with 124 gallons of water for use.

In South Africa, the dipping of stock is aimed primarily at three particular species of tick, namely the Red-legged Tick (*Rhipicephalus evertsi*), which conveys biliary fever from horse to horse; the Blue Tick (*Boophilus decoloratus*), which conveys redwater fever of cattle; and the Brown Tick (*Rhipicephalus appendiculatus*), the disseminator of East Coast cattle fever. As the latter tick seeks different host individuals in the larval, nymphal, and adult stages, and rarely remains upon one host longer than three to five days, short interval dipping is necessary, the animals being dipped at intervals of three or five days. Consequently, in order to avoid "scalding" the animals by such frequent dipping, the so-called "Laboratory Dip" formulae have been devised, based upon the principle of using a mixture of commercial sodium arsenite and paraffin emulsion.

The dips recommended are those designed by Pitchford in Natal, as follows:

| | 3-day Interval. | 7-day Interval. | 14-day Interval. |
|---|---|---|---|
| Sodium arsenite . . | 4 lbs. | 8 lbs. | 12 lbs. |
| Soft soap . . . . | 3 lbs. | 3 lbs. | 6 lbs. |
| Paraffin . . . . | 1 gal. | 2 gals. | 2 gals. |
| Water . . . . | 400 gals. | 400 gals. | 400 gals. |

Such emulsification permits the use of a lesser percentage of arsenic content, without loss of toxic efficiency, and so reduces the risk of scalding the cattle. Cooper and Laws (1913) find that an emulsified solution of sodium arsenite containing the equivalent of 0·153 per cent of $As_2O_3$ is as efficient as a non-emulsified solution containing 0·225 per cent of $As_2O_3$. Many proprietary dips are prepared from formulae based upon this emulsification principle. Thus one well-known trade dip would seem to be a dilute solution of an arsenious ester of glycerine produced by heating excess of glycerine with arsenious oxide. Another one consists of a mixture of castor-oil soap and sodium arsenite heated together, allowed to solidify, and ground to powder.

The strength of the dipping solution, when once made

up, is liable to be affected by three factors. There is, in the first place, the gradual concentration brought about by evaporation of water from the tank ; there is, secondly, an occasional dilution owing to heavy rain ; thirdly, there is a lowering of toxic efficiency owing to the oxidation of arsenite to arsenate.

It would seem possible to allow for loss by evaporation by marking the level of the dip on the side of the tank before a period of disuse, and then filling up to this mark again with water before using; but, as pointed out by Chapin (1914), it is difficult to construct a three-thousand-gallon tank that is entirely water-tight, so that it is usually impossible to determine how far a lowering of the level of the fluid is due to actual evaporation, how far due to leakage. The only remedy would seem to be actual analysis of the fluid at frequent intervals, say once a week.

Fortunately, such an analysis is not a matter of very great difficulty. A simple and practicable method of estimating the percentage of arsenic oxide equivalent in the tank fluid is described by Facer (1920), and is based upon the property possessed by arsenic oxide of absorbing iodine in a certain definite proportion.

A sample of tank fluid is taken, any free soda neutralised by addition of sulphuric acid, and the liquid filtered from sediment. 50 c.c. of the filtrate is taken, any surplus of acid neutralised by addition of sodium bicarbonate until there is no further effervescence, and a little "Gloy" or starch paste added. Iodine solution of known strength is run into the beaker containing the sample until a permanent blue tinge is obtained. The amount of iodine absorbed is then read off the graduated burette containing it, and the amount of arsenic oxide equivalent in the 50 c.c. of dip calculated.

As regards the oxidation of arsenite to arsenate, a satisfactory remedy has yet to be found, nor has it been definitely established whether the cause lies in atmospheric influence or in the agency of micro-organisms. Green (1918) claims to have isolated several arsenic-resistant organisms from a cattle-dipping tank, and postulates an oxidising organism (*Bacterium arsenoxydans*) converting arsenites to arsenates, and a reducing organism (*Bacterium arsenreducens*) belonging to the colon-typhoid family and able to reduce arsenates to arsenites. He describes also the occurrence of other resistant organisms, including members of the *putridium* group, neither oxidising nor reducing arsenical salts.

Whatever the cause may be, there is no disputing the fact that this oxidation phenomenon lowers the efficiency of the dipping fluid. It has been shown conclusively that sodium

arsenate has only half the killing power of the arsenite (Laws, 1913), and remedial measures are urgently needed.

Chapin (1915) recommends the addition of 37 per cent solution of formaldehyde, one gallon to fifteen hundred of dip. Williams (1914) would add carbolic disinfectant, one or two gallons per thousand of fluid. Holborow (1915) asserts that the addition of formalin, corrosive sublimate, carbolic, or boric preparations is useless, but that addition of potassium cyanide materially reduces oxidation; so small a percentage as 0·05 of this chemical in the dip reduced the amount of oxidation from 83 to 13 per cent.

One very practical method of diminishing oxidation is to agitate the solution constantly, by passing cattle through it at regular and frequent intervals.

The toxic action of arsenical dips is not very clear. The formerly prevalent opinion that the tick absorbed the poison through its skin does not fit in with experiments such as those by Blacklock (1912), who immersed specimens of the tick *Ornithodoros moubata* in solutions of various commercial dips (Cooper's, Little's, Savar's, Hayward's Yellow Paste, and MacDougall's) for an hour or more, in many cases without toxic effect.

It would seem more probable that the tick sucks in the poison with the blood of the host. It has been asserted by Cooper and Laws that up to a certain limit the skin of a mammal possesses a certain affinity for arsenic, but beyond this limit the surplus arsenic enters the peripheral blood circulation and so can be sucked in by the tick. Arsenical solutions applied to the skin of an animal penetrate the cellular tissues by osmosis, and, as the amount of arsenic absorbed by the skin is cumulative up to a point, it is possible by repeated dippings in low-strength solution to render an animal poisonous to all ticks, and yet avoid any scalding effect. Such short-interval dipping, say twice a week, has in practice proved to be most effective (Theiler, 1913).

**Carbolic dips** consist usually of a mixture of phenols and cresols, of pyridine and its basis, or contain coal-tar creosote as the main ingredient; thus a well-known proprietary carbolic dip consists of creosote dissolved in castor-oil soap, plus an addition of cresylic acid.

Such dips are without doubt poisonous to sheep-scab mites and do not cause wool-injury; but their effect does not last very long, and it is difficult to gauge the strength of the dipping solution. Some authorities assert also that sheep receive a greater set-back from their use than with other types of dip. Their value against ticks seems doubtful.

Apart from several excellent proprietary brands, the use of carbolic as well as arsenical dips may be said to have given place in the United States and South Africa especially to the vastly cheaper type of dip discussed below.

**Sulphur dips** may be described as dipping fluids in which the principal ingredient is a combination of sulphur and an alkali, or sulphur and nicotine.

Few objections have been brought forward against this type of dip, but such objections as there are would seem to be so important that if irrefutable they would tend to show that sulphur dips are not only useless but actually dangerous to use.

The main objections alleged are:

1. Sulphur dips will not cure sheep-scab.
2. Sheep die from such dipping if recently sheared.
3. Such dips injure the wool.

The first objection is refuted by Australian experience. One result of the big outbreak of sheep-scab in New South Wales in 1863 was the passing of a Quarantine Act prohibiting the use of all specifics, proprietary or otherwise, except the formula adopted and recommended by the Government, namely a dip containing sulphur and tobacco. In eighteen months the disease was completely eradicated, and in 1866 the Colony was declared clean. The formula adopted was: tobacco leaves 1 lb., flowers of sulphur 1 lb., water 6 gallons.

The tobacco is infused in lukewarm water for twenty-four hours, the infusion brought up to boiling-point and allowed to stand overnight. The sulphur is mixed into a gruel in a bucket of water, and added to the strained tobacco infusion. The mixture is well stirred and the remaining amount of water added.

The second objection has a certain amount of truth in it, but deaths from dipping have been found invariably to be due to shear-cut sheep being immersed in stale dip. It is doubtful whether freshly prepared lime-sulphur dip, prepared according to a recognised formula, would affect shear-cut sheep, but it is safer to allow a short time to elapse between shearing and dipping.

The objection concerning wool-injury applies more particularly to sulphur-alkali dips than to sulphur-nicotine preparations. The question has been taken up by Green (1915) in his very thorough investigation of the chemistry of sulphur dips. According to this authority, a fluid prepared by the interaction of caustic soda and sulphur consists of a mixture of sodium pentasulphide and sodium thiosulphate;

if prepared by the interaction of lime and sulphur, the fluid is a mixture of calcium pentasulphide and calcium thiosulphate.

No monosulphide can be detected, and of sulphate only a trace. The more important constituent would appear to be the pentasulphide, for the thiosulphate alone is ineffective.

Solutions of pentasulphide of a strength used in dipping have no action upon wool even after prolonged steeping. On fleeces of dipped sheep the pentasulphide is rapidly oxidised to thiosulphate without any depilatory by-products being formed. An excess of free alkali, however, brings about formation of a monosulphide which does injure wool; but as the amount of alkali would have to exceed 10 per cent, only gross carelessness in the preparation of the dip could bring about the possibility of injury to the animal or its fleece.

### Preparation of Sulphur Dips

Sulphur dips are of four kinds, the sulphur being combined with:

(*a*) *Lime,* boiling being necessary.
(*b*) *Caustic soda,* the heat of reaction sufficing.
(*c*) *Alkaline carbonates* (sulphur-loogas dip).
(*d*) *Tobacco.*

*Lime-sulphur dips* should contain at least two parts of sulphur to one of lime, and should be used at a temperature of 95-105 degrees F.

A formula recommended by Imes (1918) is as follows: 12 lbs. unslaked lime or 16 lbs. commercial hydrated lime is made into a thin paste with water; 24 lbs. flowers of sulphur should be precipitated into the paste and the mixture churned up to the consistency of mortar. This is then added to 30 gallons of water whilst boiling, care being taken not to interrupt the boiling, which should be allowed to continue for one and a half to two hours, until the liquid is amber-coloured. The preparation is allowed to cool and settle, and for use is diluted with warm water to make 100 gallons of dip.

Chapin (1916) gives a working formula: 8 lbs. unslaked lime, 18 lbs. sulphur, boiled together for an hour with rather more than 10 gallons of water until by evaporation a final volume of 10 gallons is reached. When used, it should be diluted at the rate of 1 gallon to 9 or 10 gallons of water for sheep, 1 gallon to 7 or 8 of water for cattle.

*Soda-sulphur dips* are more easily prepared, since the heat of the reaction is sufficient to do away with the need for boiling. Large excess of free sulphur is advisable in the formula in order

to counteract carelessness in the addition of alkali. The formula recommended by the Agricultural Department, Union of South Africa, is as follows: 5 lbs. caustic soda, 20 lbs. sulphur, $2\frac{1}{2}$ to 100 gallons of water.

The most important point in its preparation is the careful preliminary mixing of the sulphur with water to form a smooth cream, since the reaction depends upon the intimacy of contact of the sulphur with the caustic soda solution.

Five pounds of soda neutralise only seven and three-quarter pounds of sulphur, so that as twelve and a quarter pounds of sulphur remain in excess little free caustic soda should remain. The reaction will take place at a comparatively low temperature, and at 50 degrees C. may be completed in forty minutes, but it is better to use boiling water or to boil the correctly mixed preparation for ten minutes. If the sulphur be not wetted in mixing to a cream, it tends to float on the surface, to form into lumps, and to escape combination, but this may be avoided somewhat by adding the caustic soda slowly.

**Nicotine dips** should not contain more than 0·05 per cent of nicotine, and should be used at a temperature of 100 degrees to 105 degrees F. Imes (1916) recommends: 16 lbs. of sulphur, $\frac{2}{5}$ lb. of nicotine (40 per cent solution), 96 gallons of water.

The formula suggested by the Board of Agriculture for Great Britain requires: 35 lbs. waste tobacco steeped in 25 gallons of water for four days. The infusion is strained and the last proportions of the extract removed by pressing the residual tobacco. To this extract 10 lbs. of flowers of sulphur are added, the mixture well stirred and diluted to a volume of 100 gallons.

### Dipping Tanks

The application of such insecticidal fluids as have been discussed above to animals is effected usually by submerging the animal in a bath of the substance. Spraying such fluids upon animals can also be employed, but is only advisable where owing to shortage of water the submersion-method is impossible.

When only a few animals have to be dipped, a portable galvanised-iron dipping tank may be used (Fig. 9, *a*). The tank is imbedded in the ground so that its edges are flush with the ground level. It may be noted that one end of the vat is inclined at an angle of 30 degrees, so as to form an exit slope.

In the case of sheep, dipping of a few animals can be carried out by using a dipping bag of heavy canvas, four feet deep and eight in circumference. The bag is filled with dipping fluid and the sheep is placed within it, rump first and hind feet tied,

by one man, assisted by another man who holds the bag up round the animal.

In the treatment of pigs, the habit of the animal to wallow in water during warm weather may be taken advantage of, and artificial hog-wallows containing a few inches of medicated water can be provided. The wallow is about nine feet long by five feet wide, one foot six inches deep, with a four-foot inclined slope at one end. It is sunk into the ground so as to project four inches above the surface. The main precaution is to avoid having the layer of water too deep, otherwise the pig will not roll in the liquid properly. For pigs of various sizes a suitable depth of liquid is three to four inches. The insecticide should not be constantly present or the animals will refuse to wallow; one application per week is sufficient, the wallow being charged with water between the applications. The tendency for pigs to drink from the wallow can be prevented by treating the water with some distasteful substance. Crude petroleum is very suitable, being an excellent insecticidal dressing as well as rendering the water distasteful, and may be added to the water in the wallow at the rate of one quart per pig.

Another method is to provide posts driven into the ground, the protruding portion wrapped round with sackcloth soaked in crude oil. The pig will learn to rub against these posts and so smear the affected parts of its skin with oil.

Where large numbers of animals have to be dipped, however, a permanent dipping plant is essential. Such a plant must comprise a tank large enough to accommodate the type of animal to be dipped and to hold several swimming animals at once, and must comprise arrangements for handling the animals at each end of the tank.

A dipping plant (see Fig. 9, *b*, *c*, *d*) consists, in fact, of the following parts:

1. A *collecting pen* (English and Australian term), large enough to accommodate the largest herd that may require dipping.
2. A *running chute* (race), a passage scarcely wider than the animal leading from the pen to the dipping vat. It is made preferably to slope slightly uphill, and ends in
3. A short downwardly inclined board called the *slide* so that the animal slides suddenly into the vat. A piece of boiler plate makes a good slide-board.

   Now, the hardest work in dipping is to persuade the animal to come up to the slide. Sheep in particular that have been dipped before are very wary and stubborn, and require much forcing along the race to the slide. It is very desirable, therefore, that the animal should not

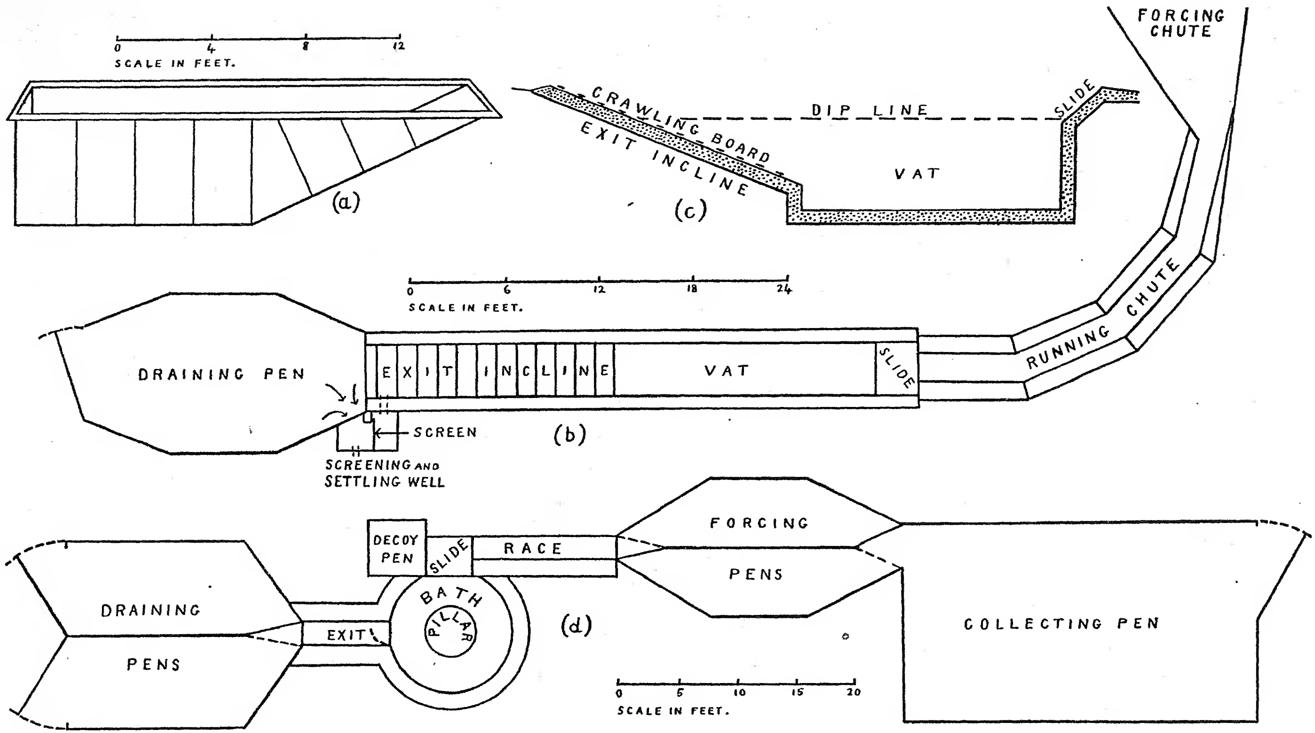



FIG. 9.—(*a*) Portable galvanised metal dipping vat; (*b*) cattle dipping plant with cement vat; (*c*) longitudinal section of vat. (After U.S. Dept. of Agriculture: Bureau of Animal Industry.) (*d*) Sheep-dipping plant. (After Department of Agriculture, Victoria, Australia.)

see the vat until it is too late to save itself from sliding in. The American system is to make the approach to the vat somewhat curved so that the vat is not visible until the animal is nearly up to it. Somewhat better is the Australian type of dipping plant, figured in Fig. 9, *d*. Here a decoy pen is provided; the sheep coming along the race sees before it, not the vat, but its fellows in the decoy pen. Just as it reaches the pen it slips sideways down an inclined slide into the vat. A curtain may be used to prevent any side view of the vat.

4. The *vat* may be long and narrow, forcing the animals to swim in single file, or it may be circular and narrow. The advantage gained by the latter principle is that the animal can be made to swim round and round the vat as long as is considered advisable, whereas with the rectangular vat there is always a certain amount of doubt as to whether the animal has been immersed long enough. For cattle the rectangular type is probably the more convenient; for sheep the circular type would seem preferable, since an animal suffering from sheep-scab ought to be immersed for at least three minutes.

   The vat may be constructed of wood, of riveted iron plates, or of concrete. It should be built on ground-level near to a good water supply, but not on marshy nor water-logged ground. The direction of the vat should be north and south, with the entrance at the south end, as animals enter more willingly with the sun at their backs. The edge of the vat may be flush with the ground and fitted with lateral splash-boards, or may be raised nine or eighteen inches above the surface. The sides of the vat should slope slightly outwards, and a slight inclination of the floor towards one end is a help in future cleaning of the vat.

   At the opposite end of the vat to the slide is:

5. The *exit incline* or crawling-board, an inclined platform about sixteen feet long provided with cross-cleats, up which the animal passes into

6. A *draining pen*. Draining pens are absolutely essential. There should be two, so that when one is full it can be closed and the other one worked. The floor may be of wooden battens raised about a foot above a sloping floor of corrugated iron, which conducts the drainings *via* gutters into a well about two feet square, covered with a strainer to intercept filth, and opening into the vat; or the floor of the draining pen may be of roughened concrete sloping from the middle line to lateral gutters.

Where lime-sulphur dips are used, the provision of cooking and settling tanks is necessary. These may be heated by steam pipes or by a fire-box. Steam can be piped, if a steam boiler be used, into the dipping vat so as to maintain the temperature of the dip, as well as into the cooking tanks to boil dip or heat water.

The proportions of respective parts of a dipping plant vary with the type of animal to be dipped, but generally speaking are as follows :

| | Horses and Cattle. | Sheep. | Pigs. |
|---|---|---|---|
| Receiving pens | .. | .. | .. |
| Running chutes—length | 20-30′ | 20′ | 20′ |
| width | 30″ | 22″ | 18-22″ |
| height | 40″ | 40″ | 40″ |
| Vat—length | 24-100′ | 30-100′ | 20-40′ |
| depth | 7′ | 5′ | 4′ 6″ |
| top width | 3′ | 2′ | 2′ |
| bottom width | 18″ | 8″ | 6-12″ |
| depth of liquid | 70-80″ | 40-48″ | 40-48″ |
| length of slide | 2′ at 45° | 2′ at 45° | 2′ at 45° |
| length of exit incline | 12-16′ | 8-16′ | 10′ |
| Dripping chute (cattle) or Draining pen (sheep) | 20-40′ × 30′ | 32′ × 16′ | 12′ × 8′ |
| Holding pen | .. | .. | .. |

## CHAPTER X

### ATTRACTANTS AND REPELLENTS

ONE of the most promising fields of entomological inquiry, from the economic standpoint, is that phase of insect physiology which deals with the reaction of the insect to the various stimuli of its environment, the likes and dislikes of the animal when subjected to sensations affecting its senses of sight, smell, touch, hearing, and so on. The general way in which the insect responds to such a stimulus may be termed a *tropism*, a term borrowed originally from the botanist, or, better still, a *sense-reaction*. Of such tropisms, the more important are *thermotropism* (response to temperature), *phototropism* (to light), *geotropism* (to gravity), *stereotropism* or *thigmatotropism* (to contact), *rheotropism* (to currents of air or water), and *chemotropism* (to chemical substances).

Such tropisms may be positive or negative, the insect may be attracted or repelled. Many nocturnal Lepidoptera, for example, are positively phototropic to a source of intense light such as an electric arc, but are negatively phototropic to sunlight. Many insects are positive to the less refractive colours of the spectrum, to yellow and green. Soil insects are generally negatively phototropic.

Response to light determines the choice of location for many insects—forces some to live in full light, others in darkness : some have to seek food during the day, others by night.

In Alberta, larvae of the Army Cutworm (*Euxoa auxiliaris*) are negatively phototropic and hide beneath the soil until four or five o'clock in the afternoon, when they come to the surface to feed. In the weaker light of sunset they are positively phototropic, migrating in a westerly direction towards the setting sun. When food is scarce, however, hunger overcomes the aversion to sunlight to some extent, and the larvae come above-ground, but the retention of the negative phototropism is still shown in that they tend north-westerly in their movements (Hewitt, 1917).

Positive phototropism may not be equally developed in both sexes of an insect species. The interesting experimental data obtained by Vermorel and Dewitz (Dewitz, 1912) by observing the degree of response shown by various night-flying moths to the light of an acetylene lamp, would seem to indicate that the relative proportions of the sexes thus attracted are not equal, but are in a definite ratio, constant within the limits of each Lepidopterous family. Thus among the Bombycidae the percentage of females caught was 4; Noctuidae showed a 19 per cent proportion of females; Geometridae, 27 per cent; Tineina, 39 per cent. The percentage of females probably decreases with the temperature; possibly peculiar, as yet unknown, atmospheric conditions affect the flight tendency of nocturnal insects according to sex.

Positive stereotropism is seen in the gregarious habits of many insects, and in the tendency of soil insects to insert themselves into crevices, into soil, or under stones, to have their bodies in contact with something solid.

Positive rheotropism is seen in the behaviour of many insects which float upon or glide upon a water surface, or in the air, with their bodies head on to the prevailing current. The Rocky Mountain Locust (*Melanoplus spretus*), for example, flies *with* the wind in a light breeze—it is negatively rheotropic; if the velocity of the wind increases, the insects act positively—they fly *against* the wind.

The whole subject of tropisms has been discussed from the entomological standpoint by very many observers—in particular, of recent years, by Herms (1909), Dewitz (1912), and Hewitt (1917),—and the application of such tropisms to the question of insect control has been made from time immemorial, though of course in quite empirical fashion; in fact, the bulk of insect control methods depends for success upon utilisation of this principle of tropic response, and the failure in the field of methods which are of proved merit in the laboratory is very often due to some tropism factor overlooked in the small-scale experiments.

Upon the responses of insects to temperature are based the various methods of high temperature and low temperature sterilisation; response to temperature and humidity influences very largely the distribution and migration of insect species. Moisture, whether in soil or in stored products, may be of the utmost importance in a scheme of control.

Phototropism is the basis for many ingenious light-traps, ranging from the simple lantern set in a tray of kerosene to the elaborate electric installations used in the French vineyards of Champagne for catching and destroying Vine Moths (*Clysia* and *Sparganothis*).

*Stereotropism*, again, is the basic principle of most traps—the belt around fruit trees, the use of flat stones, and boards, for example.

Many of the control methods arising from our knowledge of tropic responses, however, are discussed elsewhere in this book. In this chapter we are concerned more particularly with the control methods arising from the phenomena of positive and of negative **Chemotropism**—that is to say, with the employment of chemical *attractants* (trap baits) and chemical *repellents* (insectifuges).

### Attractants

A substance that is positively attractive to an insect may act as :

(*a*) A *food-stimulus*—may actually be, or resemble in appearance or odour, a favourite food substance.
(*b*) A *sex-stimulus*—the substance may suggest to the olfactory senses of the male insect the presence of the opposite sex.
(*c*) An *oviposition-stimulus*—may suggest by smell or taste the ideal medium for oviposition.

A *food-stimulus* probably reaches the insect almost invariably through its sense of smell. The use of traps baited with strong-smelling food baits is still a standard method of control for such pests as wireworms and cutworms. The attraction that fermenting fruits or alcoholic drinks have for flies is well known, and in recent years a considerable mass of information has been accumulated regarding the food predilections of house-flies and the application of such facts to the devising of trap baits.

Speyer (1920) has comparatively recently gone into this question, and suggests that saturated alcohols, aldehydes, and acids are positively chemotropic to house-flies when occurring as fermentation products. Alcohols, aldehydes, and acids containing the methyl group $CH_3$, and whose molecular weight is not below 30, are positively chemotropic, very markedly so where the methyl group is united to $(CH_2)_x$. Possibly this molecular group $CH_3(CH_2)_x$ is the actual food stimulus. Amyl compounds are increasingly attractive in the order in which they form during fermentation, *i.e.* the valerianic acid is more attractive than valerianic aldehyde, and this again than amyl alcohol. Compounds containing the benzene ring, and essential oils, are unattractive. Certain essential oils are distinctly negative, *e.g.* oil of *Pinus sylvestris*, orange oil, lemon oil, citronella oil, oil of juniper berries, and possibly camphor oil.

These conclusions agree fairly well with those of earlier observers, Morrill (1914), Richardson (1917), Lodge (1918), Imms and Husain (1920), Buck (1915), and with those of Atkins (1921).

The ability of the female insects of many species of Lepidoptera and Diptera to attract males from a distance is a fact long known to the entomologist. It has always been the general opinion that the stimulus reached the male through his olfactory sense, although Noel (1915) has suggested that in many cases the male is really responding not to an olfactory stimulus but to definite ether-vibrations akin to Hertzian waves or to X-rays, produced by the female.

In recent years, much interest has been excited among entomologists by the discovery that males of certain fruit-flies (Trypetidae) can be attracted by certain essential oils. Howlett (1912), experimenting with species of *Dacus*, observed that males exclusively were greatly attracted by the eugenol oils—*iso*- and *methyl-eugenol*—which are constituents of oil of citronella. Why they should be thus attracted seems somewhat uncertain, since no similar attraction is exerted by crushed females, nor have the odours of these substances been identified with those of plants upon which the fly normally breeds.

Severin, H. H. P., and Severin, H. C. (1914), have followed up this question in the case of the Mediterranean Fruit-fly (*Ceratitis capitata*). They find that the relative attraction of various oils for *male* flies is as follows, kerosene being taken as 100 per cent:

*Vegetable oils.*—Citronella 1 per cent, turpentine ·04 per cent, cocoanut 0 per cent.

*Animal oils.*—Whale 0 per cent, fish 0 per cent.

*Mineral oils.*—Naphtha 103 per cent, benzene 82 per cent, gasoline (63 degrees Beaumé) 61 per cent, gasoline (86 degrees Beaumé) 31 per cent, kerosene 100 per cent, mineral seal oil 14 per cent, colza burning oil 1 per cent, " Perfection " signal oil ·1 per cent, " Renown " engine oil ·6 per cent, Atlantic red engine oil 0 per cent, crude petroleum 68 per cent.

Here again the reason for the great attraction of kerosene and naphtha is inexplicable.

Now, the attraction of male insects, or for that matter of both sexes, is not a sufficiently sound basis upon which to lay down general chemotropic control methods. It is not a difficult matter to devise a trap that will catch numbers of fruit-flies, blow-flies, house-flies, but the devising of a trap that will attract gravid females only is a far more difficult proposition,

requiring, as it does, precise knowledge of the chemical constituent in the mixture of chemical compounds—the decaying banana, festering wound, manure heap, whatever it may be—that stimulates the gravid female to oviposit. Yet this is the type of trap that is required, and the only type of trap that is scientifically sound.

A certain amount of information has been accumulated. We know, for example, that bait traps for moths, the beer-and-treacle type of trap, often attract a large percentage of gravid females. In some cases we have a definite idea as to the chemical nature of the oviposition stimulus. In Pierid Lepidoptera it would seem to be one of the mustard oils. Howlett claims to have induced a species of *Sarcophaga* to oviposit upon the putrefaction product *skatole*, and *Stomoxys calcitrans* to oviposit upon a cotton rag drenched with valerianic acid. Richardson (1916) has obtained experimental results that suggest the stimulus to oviposition of *Musca domestica* to be ammonium hydrate or carbonate in conjunction with butyric and valerianic acids; although further work by Crumb and Lyon (1917) suggests that the carbon dioxide produced by such conjunction is the stimulus.

Our knowledge, however, is fragmentary and largely empirical, but probably the future development of this comparatively unexplored field of insect physiology will be rapid. There is a very wide scope for methods of insect control based upon precise knowledge of oviposition stimuli. Muscid Diptera in particular are among the most difficult insects to repress, such insects as the Sheep-maggot Flies (*Phormia* and *Lucilia*), Tsetse-flies (*Glossina*), Warble-flies (*Hypoderma*), and the various Acalyptrate Muscids that attack fruit and field-crops, being almost uncontrollable by present methods, and these insects particularly may be expected to respond very readily to chemical traps.

**Repellents** are substances that are not just non-tropic but are *negatively* chemotropic—that is to say, they should be not merely unattractive but should be actively repellent to any insect attracted to their vicinity from motives of curiosity. A good repellent will not merely mask the attraction-odour, as do many of the deterrents recommended against mosquitoes, sheep-maggot flies, onion flies, and so on, but should cause the insect intense sensory annoyance, should be pungent or should be viscous enough to clog its spiracles or its mouth-parts.

In practice this result is generally obtained by using pungent oils, but since such oils are always more or less volatile the majority of repellents in common use are not completely successful.

Repellents intended for application to animals differ somewhat from those intended to protect plants, but both kinds agree in having to be cheap, non-injurious to plant or animal, moderately volatile, and oily or pungent.

The most satisfactory repellents for use on animals are *castor-oil*, *crude petroleum*, and *fish-oil*, but the first of these substances is usually too expensive for large-scale use, and the second and third are apt to affect the skin of the animal. In practice, therefore, the average type of repellent for use on live-stock consists of a soap emulsion of crude fish-oil or crude petroleum, to which may be added some such substance as *naphthalene*, *crude carbolic acid*, *oil of tar*, *resin*, *sour milk*.

Certain essential oils—*aniseed*, *laurel*, *citronella*, *camphor*—are also markedly repellent to insects, but are evanescent. The consequent necessity for frequent re-application somewhat debars their employment upon cattle, but is not such a drawback to their use as *culicifuges* (anti-mosquito), and they are usually so utilised.

A large number of excellent recipes based upon these principles are available (Graybill, 1914)—excellent, that is to say, as regards their repellent qualities, but possessing in the great majority two serious drawbacks: they are too viscous to pass through a spray-nozzle, thus having to be applied by hand, and they require renewal every day or every other day.

Now, the ideal repellent for use on live-stock must retain its repellent property for at least a week whatever the weather be like; it must be applicable through a spraying syringe or as a dip—that is to say, must not be too viscous; it must be spread easily and adhere firmly to the animal's skin.

Jensen's formula (Graybill, 1914) is asserted to repel biting flies (*Lyperosia*, *Stomoxys*) and to retain its properties on dairy cows for at least a week. The preparation is as follows: 1 lb. of common laundry soap is dissolved in 4 gallons of water and added to a solution of 4 oz. of powdered naphthalene in 1 gallon of crude petroleum; the two solutions are churned together for fifteen minutes; the repellent is applied to the animal with a brush. According to Cross (1916), this formula is impracticable for use on camels in India, causing severe blistering of the skin and not being effective against Tabanid flies for longer than twelve hours.

In the case of dairy cattle, the choice of a suitable repellent is restricted somewhat owing to the risk of milk or butter being tainted. Coal-tar products, for example, have to be ruled out. On the other hand, the treatment of dairy cattle each day is not impracticable, particularly if the repellent can be passed through a spray-nozzle, since it is not absolutely necessary for

the whole of the animal's skin surface to be sprayed, but merely such portions as are inaccessible to its tongue and tail.

There are many fairly effective preparations therefore which, although requiring daily renewal, can be used for dairy cattle.

Cory (1917) recommends a 6 per cent emulsion of wood creosote: two-thirds of a pound of caustic soda (98 per cent purity) are dissolved in a definite quantity of water for each gallon of creosote to be emulsified; the solution and the creosote are churned together and the emulsion diluted with cold water until the percentage of creosote does not exceed 6. This preparation can of course be sprayed upon the cattle.

A formula recommended by the Ontario Agricultural College (43rd Annual Report, 1917) as a repellent against Horn-fly (*Lyperosia*) and Stable-fly (*Stomoxys*) is as follows: 1 gallon of fish-oil soap is dissolved in 1 gallon of hot 5 per cent soap solution (ordinary laundry soap); 1 gallon of kerosene is then mixed with 1 gallon of slightly sour milk; the two solutions are churned together, allowed to cool, and 6 ounces of oil of citronella are added. This stock solution is diluted with twice its volume of water for use.

Several formulae for repellents against the Screw-worm Fly (*Chrysomyia macellaria*) and the various Sheep-maggot Flies (*Phormia regina* and *Lucilia sericata*), which cause great losses among cattle and sheep, are given by Babcock and Bennett (1921), from the Texas Agricultural Experimental Station. Of these, the most promising are as follows:

(*a*) Powdered alum 80 parts, zinc oxide 60 parts, boric acid 30 parts, gum camphor 6 parts.

(*b*) Gum camphor 5 parts, powdered charcoal 100 parts, laundry starch 50 parts, boric acid 10 parts, tannic acid 10 parts.

These two formulae are of course applied as powders.

(*c*) Pine-oil 1 quart plus machine-oil 1 quart, mixed when required with a solution of 4 oz. gum camphor in 1 lb. of chloroform, 1 part of the chloroform mixture to 4 parts of the oil mixture. This is the Parman formula.

(*d*) Pine-tar 4 oz., castor-oil 6 oz., kerosene 10 oz., turpentine 1 oz.

(*e*) Pine-tar 20 oz., glycerine 10 oz., turpentine 1 oz.

These three formulae can be sprayed.

Repellents against mosquitoes, for application to the human skin, do not usually contain such drastic ingredients as crude petroleum, fish-oil, or carbolic acid, but consist generally

of one or more pleasant-smelling essential oils, such as pennyroyal, peppermint, camphor, and require frequent renewal.

Howard (1917) recommends a mixture of oil of citronella 1 oz., spirits of camphor 1 oz., oil of cedar $\frac{1}{2}$ oz., rubbed on hands and face or placed on a towel at the head of the bed. This mixture, however, will not remain effective throughout the whole of a hot night, and so is ineffective against such mosquitoes as *Stegomyia*, which commence to bite at dawn. A mixture of citronella oil 1 oz. with 4 oz. of vaseline will be found to evaporate less quickly. A preparation that avoids citronella, which is unpleasant to many people, consists of castor-oil 1 oz., oil of lavender 1 oz., and alcohol 1 oz. Another formula, also free from citronella, is: oil of cassia 1 oz., brown oil of camphor 2 oz., vaseline or lanoline 4 to 5 oz.

In Italy a favourite anti-mosquito ointment consists of a 1 per cent solution of thymol in vaseline.

Pure kerosene is extensively used as a mosquito repellent in the Philippines, and the Bamber oil, used in Ceylon, also contains kerosene, 1 oz. of it being mixed with $1\frac{1}{2}$ oz. of citronella oil and 2 oz. of cocoanut oil, 1 per cent of carbolic acid being added to the mixture.

Malinin's liquid, recommended by Russian entomologists for spraying the atmosphere of rooms infested with mosquitoes, is apparently a turpentine extract of pyrethrum powder plus an addition of kerosene, carbolic acid, and oil of cloves or oil of cinnamon.

It may be pointed out that extensive experiments by Bacot and Talbot (1919) concerning the comparative effectiveness of a wide range of culicifuges under laboratory conditions were satisfactory to a certain extent for repellents whose active ingredients were: oil of cassia and camphor, oil of cassia and peppermint, oil of eucalyptus and citronella with phenol, crude naphthalene (coke oven) and camphor, light wood oil, oil of turpentine; but not one conferred complete protection after two hours from application.

It is doubtful, in fact, whether any chemical that is applicable to the human skin will keep mosquitoes at bay for any sufficiently useful length of time.

Repellents for the protection of plants consist frequently of crude oils or coal-tar products mixed with sand or chalk and applied to the base of the plant. A formula recommended in Great Britain, for example, against the Onion Fly (*Hylemyia antiqua*) and the Cabbage-root Fly (*Chortophila brassicae*) consists of creosote (2 parts) and chalk (98 parts). A quarter of an ounce of creosote to 12 oz. of chalk gives the correct proportion, and $2\frac{1}{2}$ lbs. is sufficient for 30 square yards. It is

applied in spring after the plants are set out, and is dusted around the seedlings with a powder gun. Two or three applications are given at fortnightly intervals (Smith and Wadsworth, 1921).

### Termitifuges

Reference has already been made in Chapter I. to the repellent effect that the sap of some woody plants appears to have against termites. It will be obvious, however, that however repugnant the juices of a growing tree may be to these insects, the timber of such a tree when dried and seasoned will tend to lose this property; and as termites constitute a most serious danger to woodwork in the tropics, it is imperative that all timber used there in building construction, railway construction, cabinet-making, or for any purpose, in fact, where the woodwork has to last as long as possible, or is particularly valuable, should be artificially treated with some substance that will deter the activities of this formidable pest.

Very many different types of such so-called " termitifuges " are in use, the vast majority being proprietary articles possessing a basis of coal-tar creosote.

Fletcher and Ghosh (1919), as the result of extensive trials in India with a series of such termitifuges, have published the following order of efficacy: hot creosote was efficient for more than 81 months; cold creosote for less than 28 months; carbolineum, 23 months; the Powell process, 21 months; lead arsenate, 16 months; mortant, 15 months; sideroleum, 14 months; microlineum, 14 months; solignum, 12 months; zinc chloride, 12 months; timborite, 11 months; lead chromate, 7 months; siderosthen, 4 months.

This list represents fairly well the nature of the different substances employed to deter termite attack.

Coal-tar products are undoubtedly the most efficient termitifuges, but the discoloration and the odour that they impart to timber limits their use to outdoor woodwork, railway sleepers, telegraph poles, and the like. Corrosive sublimate is very effective, but its cost is prohibitive for large-scale use. Zinc chloride is cheaper, but is less efficient than creosote and corrosive sublimate.

To render cabinet woods proof against termites, Snyder (1921) recommends impregnation with chlorinated naphthalene; the timber is placed in vats containing the melted wax at a temperature of 220-240 degrees F., and allowed to remain there for a time depending upon the thickness of the wood. Wood half an inch thick requires fifteen minutes.

Methods of applying these repellent solutions vary. The

repellent may be simply painted over the surface of the woodwork, a method which, however, though easy to carry out, is unsatisfactory, since termites usually tunnel into timber from below-ground. More effective methods aim at inducing the repellent fluid to enter the piece of wood *via* the tracheal vessels.

The following methods are enumerated by Rideal and Rideal (1921): The liquid may be either (*a*) made to enter by a head of fluid; (*b*) forced in by additional pressure; (*c*) drawn in by encasing the top with indiarubber or leather and establishing a vacuum above, whilst the lower end dips in the solution; or (*d*) the timber may be enclosed in a strong cylinder which is exhausted and filled with liquid several times. Another method is that of heating the timber to 100 degrees C. so as to convert the contained moisture into vapour; the whole is then at once covered by the cold solution; the steam condenses and the fluid is sucked into the timber.

The second method is the quicker to carry out, but the first is probably the more efficient.

## CHAPTER XI

### FUMIGANTS

In the somewhat loose terminology of the economic entomologist the word *fumigation* implies simply the employment of a gaseous insecticide, whether applied to a greenhouse, a bale of cotton, or a flower-bed; the word *sterilisation* implies the insecticidal or bactericidal use of a non-volatile chemical or of some physical agent such as heat. That is to say, the treatment of a garden plot with a volatile chemical substance such as carbon bisulphide would be termed soil-fumigation, its treatment with a non-volatile chemical such as corrosive sublimate would be termed soil-sterilisation.

It will be found a matter of great convenience, however, to define the term fumigation somewhat more rigidly, and to draw a more scientific line of division between fumigation and sterilisation.

**Fumigation** is essentially a chemical process, and implies the dilution or the saturation of the atmosphere of an enclosed space, such as a greenhouse, a tent enclosing a tree, the hold of a ship, with a lethal vapour.

**Sterilisation,** on the other hand, implies the penetration of a mass of substance, for example a bale of cotton, a warehouse of cigars, an insect-infested suite of furniture, or even the surface of a field, by a lethal agent which may be chemical or may be physical—hot air, steam, chilled air, X-rays, ultraviolet rays, or the like. The process is thus not essentially chemical, and an air-tight space is not always necessary.

It may be argued that this is somewhat of a hair-splitting distinction; that no radical difference can be drawn, for example, between the treatment of an unstocked warehouse with a lethal gas and the treatment of the same warehouse filled with grain or cotton. As a matter of fact, however, under two such dissimilar conditions, the technique of applying the lethal agent may differ considerably even if the same lethal agent be applicable to both cases; the difference may

be quite as pronounced, in fact, as the difference between so-called soil-fumigation and soil-sterilisation. Granting, however, that this distinction between fumigation and sterilisation is often more artificial than natural, it is undoubtedly very convenient from the point of view of discussion to separate the two processes in this way. In this chapter, therefore, the term fumigation will be understood to imply the treatment of an air-tight, comparatively empty space with a gaseous chemical.

An ideal fumigant should possess certain very definite qualities. It should in theory be violently toxic to insects, yet scarcely if at all toxic to plants or to vertebrate animals, a condition which is in practice an impossibility. It should be easily and cheaply generated, should not readily condense to a liquid condition, should not be soluble in water, and should have great powers of diffusion.

There is no known chemical vapour which possesses this ideal combination of characters, and in practice only two are known to come anywhere near the ideal; these two are *hydrocyanic acid gas* and *sulphur dioxide*, and these two gases are the fumigants most generally employed. *Nicotine* has a certain limited use as a greenhouse fumigant in Great Britain; *formaldehyde* and *carbon bisulphide* are used occasionally for dwelling-houses, but are in greater demand as sterilisation agents; *carbon monoxide* and *carbon dioxide* are employed in certain ship-fumigation processes; such substances as *chlorpicrin*, *cresol*, *nitrobenzene*, and *dichloridobenzene*, though full of promise, cannot be said to have got beyond the experimental stage.

**Hydrocyanic Acid** is, at temperatures above 26·5 degrees C., a colourless gas with a peculiar peach-blossom odour. It is extremely toxic to animals, less so to plants, can be generated very cheaply and easily, and has good powers of diffusion. On the other hand, it is extremely dangerous to the operator, is very soluble in water, and its toxic action is influenced very largely by atmospheric conditions.

It attacks the animal system in two ways, producing a paralysis of the nerve centres and an interference with the respiratory processes that causes asphyxiation of the tissues, even if excess of oxygen be present.

Upon plants its toxic action is less marked. According to Moore and Willaman (1917), the gas enters the plant tissues via the stomata or even through the cuticle if this be thin; penetration is encouraged by low temperature or excessive humidity. In the tissues the gas disturbs the respiratory enzymes (oxidases and catalases) and so affects respiration. There is produced also an increased permeability of the cell

walls, less water is taken up from the stem and more water is transpired by the leaf surfaces.

Woglum (1920), discussing the question of injury to plants by hydrocyanic acid fumigation, lays stress upon the importance of the prefumigation and postfumigation environments.

Sunshine, in his opinion, is the principal prefumigation factor that predisposes to injury, and would seem to be particularly dangerous when in conjunction with high temperatures. As a postfumigation factor, also, it will predispose towards injury. High temperature in the absence of sunlight is not so dangerous as many observers assert, but the temperature after fumigation should not exceed 80 degrees F. That is to say, the optimum environment for plant safety, before, during, and after fumigation, may be laid down as diffused light or darkness at uniform temperatures below 80 degrees F.

Mild fumigation generally produces a temporary wilting of the plant; severe exposure to the gas, however, causes the wilting to be followed by tissue-disintegration and death. It is, however, not wise to condemn injured plants too quickly, since, a few hours after fumigation, oxidase activity becomes normal again and catalase and respiratory activities may even exceed normal. Photosynthetic action which has been suspended begins again, but may not completely recover for several days. The rate of growth and fruit production, particularly in the tomato plant, may also exceed normal for a few days, a result brought about possibly by the increased catalase action and by the increased cell permeability, which allows readier exchange of foodstuffs and gases.

Hydrocyanic acid gas is most conveniently prepared by the action of a dilute acid upon a cyanide or a ferrocyanide. In practice, the acid used is *sulphuric*, and the cyanide that of *potassium or sodium*, in accordance with the formula

$$2KCN + H_2SO_4 = K_2SO_4 + 2HCN.$$

Pure sulphuric acid contains 96 per cent of $H_2SO_4$, but owing to the presence of impurities, such as sulphate of iron, the acid value of commercial acid averages 93 or 94 per cent.

Commercial potassium cyanide is generally about 98 per cent pure. Using these materials, each ounce of cyanide will require four-fifths of an ounce (avoirdupois) of acid; in practice one ounce of potassium cyanide to one fluid ounce of acid may be taken.

The acid is diluted with water. There are several reasons for so doing. Pure concentrated sulphuric acid acting upon a cyanide will generate, not hydrocyanic acid, but the gas known as carbon monoxide, owing to the decomposition of

the hydrocyanic acid first formed. If water be present in equal proportion to the acid, however, nearly pure hydrocyanic acid is evolved. Another advantage conferred by the presence of water is that the lumps of cyanide are disintegrated somewhat and the reaction goes on more quickly. Again, the water dissolves the potassium sulphate produced, as fast as it forms, and prevents it from coating the pieces of cyanide. If the amount of water be not sufficient to dissolve the sulphate, the latter usually solidifies, completely encloses the remaining potassium cyanide and so brings the reaction to a standstill, a phenomenon termed "freezing."

This always occurs if equal amounts of cyanide, acid, and water are used.

Theoretically, two parts of water to one part each of potassium cyanide and sulphuric acid will produce the maximum amount of available gas, but in practice this 1-1-2 formula cannot be employed; the water is not sufficient to hold the sulphate in solution long enough to prevent freezing. With three parts of water this seldom happens, so that the working formula may be taken as 1-1-3. If, as is more usual nowadays, the sodium cyanide be made use of, the working formula to be taken is 1-1½-2, *i.e.* one part sodium cyanide, one and a half parts acid, and two parts water. Whatever kind of cyanide be used, it is most important that it be as free as possible from sodium chloride and sodium nitrate. Sodium chloride, in fact, must not exceed 1 per cent, since its presence leads to very marked decomposition of the hydrocyanic gas produced.

### Technique of Fumigation

The credit for first indicating the value of hydrocyanic acid gas as a fumigant against pests is claimed by Mr. D. W. Coquillet of the Bureau of Entomology, United States Department of Agriculture, who in 1886 discovered the gas to be a most efficient insecticide for the Scale insect pests of citrus trees in California. It came into use as a citrus fumigant with surprising rapidity, and was afterwards extended to the treatment of deciduous trees, to the fumigation of greenhouse plants, to the sterilisation of imported nursery stock, cotton, etc., and to the fumigation of warehouses, granaries, ships, etc.

Broadly speaking, the gas is at present extensively used for:

(*a*) The tent fumigation of fruit trees, in particular against the Scale insect pests of citrus trees.
(*b*) The fumigation of greenhouses, against a variety of pests.
(*c*) The fumigation of ships, dwelling-houses, mills, warehouses, etc., where no plants are present.

*Tent Fumigation* of citrus trees with this fumigant has been practised in California for more than thirty years. The method consists in principle of covering trees with cotton cloth tents and introducing the gas into the tents. After exposing a tree to the gas for about an hour, the tent is removed to the next tree and the process repeated. When the method was first introduced, large cumbrous bell-shaped tents were employed, their mouths being kept open by a circle of three-quarter-inch gas-pipe; these were lowered over the trees by a derrick carried upon a wagon. This slow and clumsy method has long been superseded by the use of sheet tents. These are sheets of cotton cloth, octagonal in outline (Fig. 10), and having a diameter, from one parallel side to another, of 17 to 84 feet. The most convenient sizes are the 20 feet, the 34 feet, and the 45 feet, and an outfit for an orchard will number thirty sheets per thousand trees. The cloth used is a very tightly woven cotton drill, the cloths being spoken of in ounces, the number of ounces given being the weight of a yard of cloth 30 inches wide. Seven to eight ounces is the usual type of cloth adopted. The material being only 30 inches wide, the tents have to be made of parallel strips whose edges overlap half an inch and are double-stitched. Full details of construction will be found in the well-known bulletin of Woglum (1911).

The material composing the tent has, of course, to be as gas-tight as possible, and no fabric can be woven so as to be perfect in this respect. Many suggestions as to rendering the cotton cloth gas-proof by treatment with linseed oil, flexible paint, glue, etc., have been made and carried out, but experience in the field has shown that to make a fabric more gas-tight than is possible by weaving, requires a method of treatment which always renders the tent heavier and stiffer. Heavy tents are difficult to manipulate and are apt to injure the trees; stiff tents do not lie close to the ground and allow gas to escape. Treated cloths are also difficult to repair. In the case of small tents or of box tents for placing over small plants, gas-proofing is, however, quite advisable, and the following formula is recommended by Woglum for proofing such tents. The cloth is sponged over with a varnish prepared by heating together at a temperature of 130 to 200 degrees F., for six or seven hours and with constant stirring, a mixture of 100 parts of linseed oil, 4 parts of litharge, and 1 part of umber. The varnish is applied as a thin coat on each side of the material and well rubbed in by hand; two weeks are allowed for drying.

The tents are placed in position over the trees by the use of two poles, or in the case of large-size tents, two derricks.

The necessary calculation of the cubic contents enclosed by a tent when in position over a tree is a matter of some difficulty A tent enclosing a citrus tree, however, bears a certain resemblance to a cylinder surmounted by a hemisphere, so that if the height and width be known the cubic contents can be calculated. The determination of the height and width

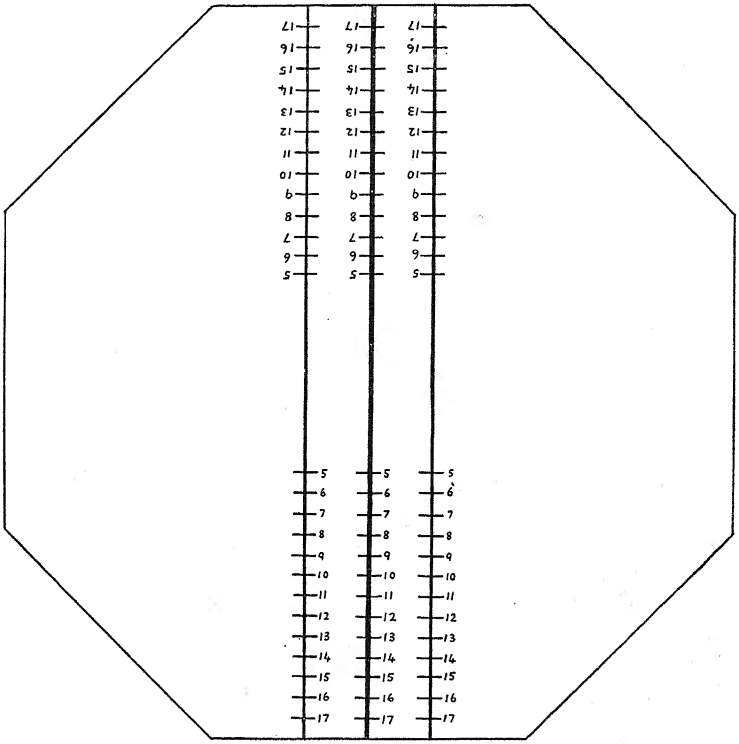



FIG. 10.—Tent sheet marked according to Morrill system. (After Woglum.)

of a tent-covered tree is not an easy matter to carry out quickly and accurately. It is more practicable to take as factors the distance round the base of the tent and the longest distance over the top of the tent, and then to employ a formula such as Woglum's,

$$\frac{C^2}{4\pi}\left(\frac{O}{2}-\frac{C(3\pi-4)}{12\pi}\right),$$

where C = circumference of the tent, and O = distance over the top of the tent, or to make use of one of the prepared schedules

where the dosage in ounces of cyanide is given for various combinations of C and O. Estimation of the distance over the top of the tent is facilitated by the Morrill system of marking the tent (Fig. 10). Three parallel black lines are marked upon the tent sheet, the middle one passing through the centre of the tent canvas, passing over the top of the tent from the edge of one side to the edge of the opposite side. These lines indicate the direction in which the tent should be pulled on or off the tree. Beginning at the centre, the lines are graduated in feet towards either edge of the tent. When one of these lines is over the middle of the tree, the distance over can be calculated by merely adding together the two numbers, on opposite sides of the tent, nearest the ground.

The distance round the base of the tent is readily estimated by the aid of a graduated tape attached to an iron stake three to four feet long. The stake is pushed into the ground at one end of the middle marked line on the tent, and the operator walks round the tree, allowing the tape to slip through his hand as he moves. When he reaches the stake again, he reads off the tape distance shown on the tape, takes rod and tape attached to the next tree and continues as before.

**Greenhouse Fumigation** is one of the simplest operations in fumigation. It is important, of course, to make the house as gas-tight as possible by covering over all cracks, crevices, keyholes, etc., with paper. The ventilators should if possible be arranged so that they can be opened from the outside after the fumigation is over. The cubical contents of the greenhouse may be calculated as follows, the description and diagrams being based upon those in the bulletin of Sasscer and Borden (1917).

To obtain the volume of a lean-to house (Fig. 11, A) multiply the sum of the rectangle X and the right-angled triangle Y by the length of the house. For example, in the diagram, $X = 5 \times 15 = 75$ sq. feet, $Y = 8 \times 15 \div 2 = 60$ sq. feet: the sum total therefore is 135 sq. feet, which when multiplied by 100 feet, the length of the house, gives the cubic capacity as 13,500 cubic feet.

Similarly the volume of an even span house (Fig. 11, B) may be obtained by calculating the number of square feet in the rectangle X and in the right-angled triangles Y and Z, and multiplying the sum of the three by the length of the house. Thus in the diagram $X = 5 \times 20 = 100$ sq. feet, $Y = 5 \times 10 \div 2 = 25$ sq. feet, $Z = 5 \times 10 \div 2 = 25$ sq. feet: the sum total is 150 sq. feet, which when multiplied by 100 feet, the length of the house, gives the volume as 15,000 cubic feet.

It is not necessary to allow for the space taken up by the benches, pots, etc.

The opinion at one time was that fumigation of plants when moist conduced to injury, owing to the solubility of the gas in water, but present-day opinion is opposed to this view. Moisture is not of importance as a prefumigation factor so long as the temperature of the house does not exceed 70 degrees F. At the same time, it must be considered that excessive moisture lessens the effectiveness of the fumigant, so that it is advisable not to syringe the plants within five or six hours of fumigation. The operation should be carried out not earlier than one hour after sunset, and should not be attempted during extremely cold nights nor during hot, damp nights.

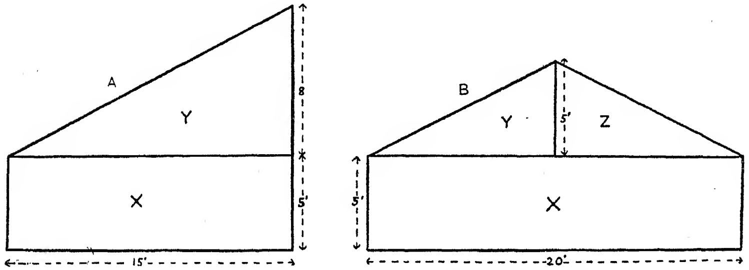



FIG. 11.—Diagram showing method of calculating the capacity of glasshouses

**House Fumigation** is similar in technique to greenhouse fumigation, but as there is no fear of plant injury the doses and length of exposure are greater. There is the same necessity for air tightness. Doors, fanlights, and windows should be arranged so as to open from the outside; registers, fireplaces, windows, keyholes, etc., should be sealed, food-stuffs and metallic objects removed. A thick carpet of old newspapers should be placed beneath the generating pots. The operator commences at the top of the house and gradually works downwards. Exposure is usually for a period of twenty-four hours (Lefroy, 1917).

### Generation of the Gas

Hydrocyanic acid gas may be introduced into the space that is to be fumigated in three ways:

1. It may be generated within the enclosed space, the "pot" generation method.
2. It may be generated in a special generating chamber and introduced into the space as a gas.
3. It may be introduced into the enclosed space as a fine mist of anhydrous hydrocyanic acid which rapidly volatilises, the "liquid hydrocyanic acid" method.

The *pot-generation method* is one of the oldest of fumigation methods and is still in common use for small-scale fumigations. It consists in principle of having a certain number of earthenware vessels or "generators," placed at intervals of 25 feet along the floor of the enclosure. Each pot contains a measured quantity of sulphuric acid and water, the acid having been *added to* the water, not *vice versa*. The generator is really a large jug of half to one gallon capacity, preferably with a rounded base and preferably having a hinged copper lid, much like the cover of a hot-water jug, perforated or corrugated to allow escape of gas. The cyanide, which should be in lumps about the size of a walnut, is weighed out and the requisite amount per generator is placed beside it in a little paper bag. The operator walks rapidly through the chamber, gently dropping each bag into the generator, or a system of strings and pulleys may be improvised to lower the bags into the generators.

The cyanide should be added whilst the mixture of acid and water is hot. It should never be added to the generator before the acid has been added. Powdered cyanide is dangerous to use owing to the violence of the reaction. The number of generators will depend upon the size of the enclosure to be treated. Generally one generator for each ounce of cyanide will tend towards a better diffusion of the gas than when fewer generators are used.

(2) Portable machines for generating gas outside the enclosure to be treated came into use about 1912; they were first introduced to supplant the "pot" method in connection with the tent-fumigation of citrus trees, but are now becoming superseded in this connection by the liquid hydrocyanic acid method.

The advantages of the portable generating machine are the accuracy with which the dosage can be estimated, the economy of labour, time, and material, the rapidity with which the gas can be generated, the freedom of damage from acid splashing.

They are used extensively at present where large spaces, such as holds of ships, railway sheds, cotton sterilising chambers, have to be rapidly filled with gas.

The principle consists in the action of acid upon cyanide dissolved in water. There are various types of machines on the market, but the majority consists in principle of a chamber, generally a cylindrical drum, containing the diluted acid. The cyanide solution is pumped into this chamber, through a pump graduated in ounces of solid cyanide, from an upper tank, and the evolved gas is conveyed to the fumigation chamber by a flexible tube.

An ingenious type of bomb-generator has been described by Mally (1917) for the fumigation of vines in South Africa. It consists of a cylindrical box of lead; the upper part forms a lid and has a number of lateral holes; attached to the inside of this lid so as to project down into the box are two graduated tubes. The lid is removed, held upside down, and the tubes charged with the requisite quantities of cyanide solution and diluted acid. The body of the box is replaced, the whole being still held in the inverted position. The cylinder is now quickly placed beneath the oiled canvas cover used in vine treatment and rapidly turned right side up. The gas is instantaneously generated and escapes in jets through the lateral openings.

(3) Both pot and machine generating methods are giving way in California, where fumigation of citrus trees is the most important insecticidal operation carried out, to the use of the anhydrous or liquid hydrocyanic acid. This method is comparatively recent. The first large-scale demonstration of its possibilities was probably that carried out by Dingle of Los Angeles in 1916, but Mally in South Africa had obtained successful experimental results and described them in 1915.

Liquid hydrocyanic acid has been known in the laboratory for many years, but has not hitherto been manufactured commercially, owing to its poisonous nature, its instability, and to the lack of commercial demand for it. It is a colourless liquid, boiling at 26·5° C., the gas being rapidly given off from the surface of the liquid at this and higher temperatures, and the vapour being inflammable, so that the containers have to be kept cool. It is produced by subjecting gas generated in the usual way to a sufficiently low temperature, no increase of pressure being required. The gas is usually generated from sodium cyanide and condensed in receivers bathed in chilled brine. The condensation product is distilled to eliminate the contained water.

The chemistry of liquid hydrocyanic acid has been discussed from the insecticidal standpoint by Quayle (1919).

It is very simply applied to tented trees (Woglum, 1919). A containing tank of two gallons capacity, provided with a measuring device and a pump, is mounted on a portable platform. The liquid, after measurement into storage coils, is forcibly expelled through a short rod fitted with a mist type of spray nozzle, and quickly disappears as an invisible gas.

The great advantage of this method is that it does away with the cumbersome outfit of generating pots, sulphuric acid containers, and cyanide boxes; there is less damage to tent sheets, and greater accuracy and speed in treating the trees.

There is a greater concentration of gas in the lower half of the tent, rather than in the upper half, as there is in the other methods. This is an advantage, since infestation of Scale insects upon large citrus trees is usually most severe in the lower (most protected) part of the tree.

### Dosage

The "dosage"—that is to say, the amount of hydrocyanic acid gas to be used in a fumigation operation—is expressed usually in terms of ounces of cyanide per thousand cubic feet of space, and the length of exposure is usually expressed in hours; in tent fumigation the dosage is expressed usually in ounces per hundred cubic feet. It is difficult to lay down any general rules as to the dosage, since conditions of fumigation differ so much and since different species of insects and plants have different degrees of susceptibility.

In tent fumigation the considerable amount of leakage of gas through the fabric has to be reckoned with, so that comparatively large doses and short exposures are the rule; the average dose is about one ounce of sodium cyanide per hundred cubic feet, and the length of exposure about an hour. To obviate the loss of time that would be incurred in calculating the dosage for each individual tree, it is customary to use "dosage schedules," charts which state the amount of cyanide to be used when the distance over the tent and the distance round it are known. There is considerable variance of opinion respecting the correct method of expressing the ratio between these two measurements, but, speaking generally, small trees are dosed in proportion to their cubic volume, and large ones are dosed approximately according to the ratio of the surface of a dome-shaped figure to its cubic content. If liquefied hydrocyanic acid gas be used, as is now the prevailing practice, 18 c.c. may be taken as equivalent to one ounce of sodium cyanide (Woglum, 1919).

In fairly air-tight spaces, such as holds of ships, dwelling-houses, etc., where the plant factor has not to be reckoned with, the dosage again may be fairly large. Creel and Faget (1916) suggest $2\frac{1}{2}$ oz. of potassium cyanide per thousand cubic feet for one hour against fleas, 0·4 oz. for fifteen minutes against mosquitoes, 10 oz. for one hour against cockroaches, and 5 oz. for one hour against bed-bugs. These may be taken as representative doses.

In a greenhouse, there is usually a variety of plants varying greatly in susceptibility to the gas, and fumigation may be directed against Aphides, Greenhouse Whiteflies (*Aleurodes*),

Thrips, or against all three. Sasscer and Borden (1917) give a list of various greenhouse plants and of the dosages that can safely be applied to them.

Speaking generally, however, it may be laid down that Aphides can be controlled by a single fumigation of one quarter of an ounce of sodium cyanide for one hour; Greenhouse Whitefly by three fumigations at intervals dependent upon the length of the life-history, say twenty to twenty-seven days, each of half an ounce for an hour; on tomatoes only a dosage of one-fifth to one-quarter of an ounce is permissible, but the exposure can be increased to nine or ten hours (Lloyd, 1922). Thrips on such plants as ferns, azaleas, and lilies are controlled by one fumigation of half an ounce for one hour; the common Scale insects of greenhouses are controllable by fumigating at the rate of three-quarters of an ounce for one hour.

**Sulphur Dioxide** is the fumigant most in favour, after hydrocyanic acid gas. It is generated almost as easily as the latter, is non-inflammable, and is comparatively non-toxic to the operator, but is neither so cheap nor so effectively insecticidal and is dangerous to plant life.

Its chief use is as a fumigant for dwelling-houses and ships. It is generated generally by burning sulphur in air at the rate of three pounds per thousand cubic feet. The sulphur dioxide produced will, of course, not support combustion, so that the burning sulphur gradually becomes extinguished. Not more than six to seven pounds per thousand cubic feet can be burned as a rule unless the sulphur be mixed with an oxygen producer, 6 per cent of potassium chlorate for example, when considerably more sulphur per thousand cubic feet can be burned.

Where the gas can be obtained in liquefied or in compressed form, in cylinders, its application becomes a simple matter.

In the *Clayton process* of sulphur fumigation, in use for ship fumigation in very many seaports, the gas is produced by burning sulphur in a special generating chamber, from which a fan-arrangement propels the gas into the space to be fumigated. The apparatus is safe to use and the gas is readily generated. Three per cent of sulphur dioxide in the atmosphere for four hours is asserted to be lethal to rats and cockroaches, but in a hold containing much cargo a large amount of the gas is absorbed and the deeper recesses of the ship do not get treated properly. Sulphur dioxide is somewhat deleterious to grain, flour, and other food-stuffs.

An interesting adaptation of the Clayton process is its application, described by Viegel and Cholet (1917) of the French Army Veterinary Service, to the destruction of the

parasites of horse mange. A disinfecting chamber containing up to ten stalls is used; each stall has a window to allow the horse's head to protrude through. The space between the edge of the window and the horse's neck is closed by a cloth collar. The animal is clipped, and washed with a solution of sodium carbonate and soft soap, worked well in with a stiff brush. Next day, when the skin is thoroughly dry, the animal is placed in the fumigating chamber and exposed to 5 to 6 per cent by volume of sulphur dioxide, generated by a Clayton machine, for two hours. On leaving the chamber, the head and neck of the animal are well rubbed with carbolic oil, a solution of 1 in 10, and a freshly prepared emulsion of 3 per cent cresol is poured in the external ears. Three days after fumigation the horse is again washed.

The same method has also been applied in Germany to the problem of eradicating sheep-scab, unshorn animals being successfully exposed for forty minutes to a 6 per cent concentration of the gas.

Lornie (1921), who has tested this method on horses in Egypt during the war, states that the addition of steam effects a great improvement, by raising the temperature and so bringing about combination of the sulphur dioxide with water vapour to form sulphurous acid, which is an ideal parasiticide.

### Ship Fumigation

Although the Clayton system of fumigation is in extensive use for the fumigation of ships, there is a strong body of opinion that favours the use of other fumigants for this purpose, and a comparative summary of various other methods has been compiled by Hossach (1915).

In the *Giemsa* apparatus, for example, the fumigating agent is a mixture of carbon monoxide and carbon dioxide, prepared by passing air over burning coke.

The *Harker* process is based upon the same principle, the agent being the waste furnace gases, comprising chiefly carbon monoxide, carbon dioxide, and 10 per cent or so of oxygen.

The Harker apparatus can deliver the gases at the rate of 180,000 cubic feet per hour; it has been adopted by the United States Government for use in several American shipping ports, primarily as a fire-extinguishing method. From the entomological standpoint these fumigating methods are useless, since the gases utilised, though fatal to rats, are comparatively non-toxic to insects; the apparatus, too, is expensive.

The *Rübner* apparatus relies on the application of formaldehyde vapour at a temperature of 160 degrees F. moist heat.

The gas is generated by placing 40 per cent formaldehyde solution (formalin) at the rate of one pound per thousand cubic feet, in vessels floating in a bath of water, and adding to each pound a half pound of potassium permanganate. A violent and rapid reaction results and dense fumes of formaldehyde are evolved. Steam is admitted to the enclosed chamber until a temperature of 160 degrees F. is reached and this is maintained for four hours.

American opinion favours the use of hydrocyanic acid gas as a ship fumigant. Tests carried out at New Orleans in 1917 by Creel and Simpson (1917) regarding the relative efficiencies of sulphur dioxide and hydrocyanic acid as ship fumigants certainly favoured the latter substance, but it must be pointed out that the tests were based upon the percentage of rats destroyed.

The time required to ventilate the hold of a ship after fumigation with hydrocyanic acid gas or sulphur dioxide depends upon the size and depth of the hold, the area of hatchway, the velocity of the wind prevailing, and the humidity of the atmosphere, so that any time between an hour and half-a-day may elapse before the fumes have dispersed. It is preferable therefore to facilitate ventilation by the use of some mechanical means. Grubbs (1917) recommends the use of a gasoline driven fan worked by three motors, two of horizontal pattern (downward blast) and one vertical pattern (horizontal blast). The hold of a fumigated ship can thus be rendered safe in thirty to forty minutes.

**Cresol**, or, as it is popularly called, "crude carbolic acid," is recommended frequently as a fumigant for rooms infested with fleas, houseflies, or mosquitoes. As the necessary dosage to produce toxicity to insects is only about 4 oz. per thousand cubic feet, this substance can be used without any risk to man or domestic animals, nor do the fumes affect metal work or household articles; further, cresol is readily procurable in most countries and is comparatively cheap.

It can be volatilised by heating it in an iron vessel over a slow fire or other source of heat. It is not inflammable, but should not be poured upon the fire, as the dense black fumes then given off are absolutely harmless to insects.

A somewhat pleasanter effect can be obtained by mixing carbolic acid crystals with an equal weight of gum camphor; the acid crystals are melted by gentle heat and poured over the gum. The clear, volatile, pleasant-smelling liquid so produced (Mimms culicide) is volatilised easily over a lamp or other source of heat, the usual dosage being 3 oz. per thousand cubic feet.

**Formaldehyde** is only known in a state of vapour and in a saturated aqueous solution, "formalin," containing about 40 per cent of the gas. If an attempt be made to condense this solution, the formaldehyde is converted into an isomeric body, paraformaldehyde, a white crystalline solid. The solution or the gas is a powerful bactericide and is therefore very popular as a fumigating agent for rooms. It cannot be used, however, where there is risk of injuring plants and foliage. There are at least four methods of applying formaldehyde to room disinfection, and the following account of them is abbreviated from Rideal and Rideal (1921). The methods are:

(*a*) Vaporising paraformaldehyde by means of heat in the presence of water-vapour; the operation is carried out by means of a spirit-lamp with a metal chimney, the latter supporting a perforated metal cup at about four inches above the flame. Several types of such lamps have been patented and marketed: 10-20 grams of paraform per thousand cubic feet are necessary, and an exposure of at least six hours must be allowed.

(*b*) Spraying the walls, ceiling, and floor with the solution. A solution of 0·5-2·5 per cent is usually employed. This method is very effective in the hands of an efficient operator, but can hardly be said to come under the heading of fumigation.

(*c*) Vaporising formalin by mixing it with potassium permanganate. About a fifth of the aldehyde is oxidised to formic acid, and there is considerable evolution of heat, which vaporises the formaldehyde and the water.

(*d*) Vaporising paraformaldehyde by adding water to a mixture comprising 30 per cent paraform, 15 per cent sodium bicarbonate, 55 per cent barium peroxide. About 4 oz. of this mixture per thousand cubic feet of room space are required.

The objection to the use of formaldehyde as a fumigant against insects is the comparative slowness with which it acts, as compared with hydrocyanic acid or sulphur dioxide, and even with so long a period its toxic action on flies appears somewhat uncertain.

**Nicotine** is greatly favoured by nursery gardeners in Great Britain for greenhouse fumigation, and many proprietary nicotine fumigants have been put upon the market. The nicotine content is generally mixed with some combustible powder, such as sawdust, and moulded into the form of a cone, which when ignited smoulders slowly and gives off nicotine vapour.

In France, nicotine has been tried in tent fumigation instead of hydrocyanic acid. A ball of wood shavings about 8 in. in diameter is soaked in $3\frac{1}{2}$-5 oz. of crude tobacco juice, suspended in a wire basket in a tree, with a piece of tow to act as a wick. The tow is ignited, the opening of the basket covered with perforated gauze, and a bag tent placed around the tree. Ten minutes' exposure is allowed.

# PART III

## MECHANICAL CONTROL

## CHAPTER XII

### CULTURAL METHODS

THE importance of proper cultural methods in the control of insect pests has perhaps never been adequately realised. This may be due to the fact that the influence of cultural methods upon a particular insect, as distinct from direct preventive measures, is not easy to trace, and also because this aspect of the problem has not been sufficiently investigated. However, when it is understood that possibly 95 per cent of insects spend some portion of their life-history in the soil, it will be realised that the aim of proper cultural methods should be not only to secure good crops but also to render conditions as unfavourable as possible for the particular insect pests which are likely to attack the crops.

That cultural methods do provide conditions unsuitable, and possibly directly inimical, to insects, can be shown by comparison of the insect fauna of grass and arable land.

Land under grass, which may be considered as being the immediate precursor of arable land, bears a vegetative covering throughout a period when little, if any, vegetation exists on arable soil. Consequently food material is always present for the use of the great majority of the phytophagous insects; also, the grassland is not subjected to cultivation, and the hibernation or period of lessened activity in the insect life-cycle proceeds without interruption. On arable land, however, the winter ploughing and working of the soil either brings insect fauna nearer to the surface or buries it more deeply, the animal being either exposed to, and probably affected by, harsh climatic conditions, or destroyed through lack of aeration.

That arable soil is actually unsuitable to the existence of insect life may be inferred from the results of investigations into the faunal contents of samples of such soil, examined throughout all times of the year and from different types of land.

In such samples taken in winter and early spring, insects will be found to be either absent or very scarce ; at that time especially all circumstances seem to combine in reducing the insect fauna of arable land most drastically.

One of the foremost cultural methods which may be said to affect soil fauna is undoubtedly that of **crop rotation.** Apart from other considerations, if it were possible to grow the same crop continuously on the same land, ideal conditions would be provided for the particular pests that happened to infest that crop, since the host plant being always present, the insect would be enabled to feed and reproduce without suffering any check. Therefore, if only from the standpoint of insect control alone, it would be inadvisable to grow the same crop frequently on the same area ; other considerations, however, also render such a course inadvisable, the desirability of growing more vigorous and varied crops for example, the economy of labour and manure, or the preparation of the soil for succeeding crops. Wherever agricultural practice has existed from the earliest times, we find that crops have been and are grown in a particular order, a system of cropping termed "rotation of crops." To take, for example, some such ancient agricultural region as the British Isles, it will be found that the cultivated land does not possess the inherent fertility of virgin soil, and that continual growth of cereal crops tends to exhaust the land and results in a gradually diminishing yield. Thus the general principle of crop rotation in the British Isles is to arrange that while half the arable land is carrying cereal crops, the other half is either being cleaned by a root crop or is acquiring more plant food by the growth of a leguminous crop. The standard rotation in this area is the Norfolk or four-course rotation, since it consists of four crops of different character succeeding each other. It may be expressed diagrammatically as follows:

*2nd Year.*
**Barley.**
(Spring sown cereal crop.)

*1st Year.*
**Roots, etc.**
(Fallow crop.)

*3rd Year.*
**Clover, etc.**
(Leguminous crop.)

*4th Year.*
**Wheat.**
(Autumn sown cereal crop.)

It is found, however, that upon certain types of soil this rotation is unsuitable, and variations from it arise, chiefly in the direction of lengthening the period of the clover or " seeds " crop to two or three years, and introducing an exhausting cereal crop between roots and barley. Some soils may require even shorter rotations than the Norfolk, but these lands are generally found to be more profitably farmed if laid down to grass.

The advantage of some such system of rotation may be seen in considering the Hessian Fly (*Mayetiola destructor*), which is a pest of wheat. It will be understood that if wheat is grown in a system of rotation with other crops the fly would be unable to maintain itself whilst the other crops occupied the ground, and if a wheat crop had been severely infested, the succeeding wheat crop, say four years afterwards, would not be damaged by the offspring of the invaders. In actual practice, however, wheat in Hessian Fly regions is not grown as a rotation crop, or re-infestation comes about from neighbouring fields of wheat, so that the Hessian Fly still continues to be the world's chief wheat pest.

One of the most important of cultural methods is the adequate **preparation of the soil** for the crop. As many species of insect hibernate as adults, larvae, or pupae in the surface soil, and as other insect pests are to be found in the stubble, deep ploughing measures in autumn will either expose these insect stages to the weather or bird attack, or will bury them sufficiently deeply to prevent emergence to the surface. Deep ploughing in itself, however, cannot be looked upon as a factor in insect control, unless followed by such operations as harrowing and rolling, since the adult insect in some cases can easily emerge through *loose* soil, even if buried to a depth of six inches.

It may be necessary to regulate the time of the autumn ploughing in order to catch a particular pest at its most vulnerable stage.

Petherbridge (1920) has found, for example, that in the case of the Strawberry Tortrix (*Oxygrapha comariana*) the old beds should not be ploughed until after the eggs are laid in November, since if the ploughing is done previously the moth will probably lay her eggs on neighbouring strawberry crops or on such wild plants as *Fragaria* and *Comarum*.

In considering cultural methods from the standpoint more particularly of insect control, the question of **time of sowing** is of great importance. It has been found in the case of certain crop-pests that if the time of autumn sowing be delayed until the adult insect ceases to be prevalent, a considerable degree of

immunity from damage may be obtained. In the case of the wheat pest, Hessian Fly (*Mayetiola destructor*), for example, it is essential that the seed should not be sown until the end of the flight-period of the fly. The point of time when the fly is no longer observable on the wing is termed the *fly-free-date* and varies in different regions. Webster and Kelly (1915) have suggested that for the United States wheat should not be sown in August, and that between latitudes 44 degrees and 30 degrees N. the fly-free-dates vary from the 10th September to the 1st November, depending on the time of emergence of the fly.

Although it is necessary, if maximum control of the fly is the chief consideration, to delay sowing until the end of the flight-period, it must be admitted that such a procedure may have certain disadvantages; according to Dean (1917), the maximum crop-yield of wheat is to be obtained, in a normal season, by sowing rather earlier than the fly-free-date in many localities. At the same time, there is no doubt that in a fly-infested area sowing should be delayed as near to the fly-free-date as possible, since if carried out much earlier a severe infestation of the crop would more than counterbalance the prospective increase in yield.

It must be pointed out, too, that delayed sowing of wheat is only a precaution against the autumn brood of Hessian Fly; the crop is still liable to infestation in the spring from the main brood which may come from neighbouring infested fields, or may be an auto-infection, that is to say, may have come from self-sown wheat present at the time of the autumn sowing. The importance of the presence of such "volunteer wheat" emphasises the necessity of its destruction at the time of the autumn sowing, and affords an example of the necessity for clean cultivation generally.

In the case of spring sown crops, early sowing is in most cases an advantage, since the young plant has a chance to become established and resistant before the main invasion of the attacking pest occurs, but such early sowing should not be practised without due consideration to normal climatic conditions.

In certain districts of Scandinavia, for example, Schoyen (1918) has observed that plants from early sowing were apparently more attacked by insect pests than were plants from late sowing, this effect being due to the fact that the former class are generally checked and rendered less resistant by the spring drought.

Early sowing, by extending the period of germination, may sometimes cause the crop to be actually more susceptible to attack.

Rennie (1917) has noted that oats are particularly destroyed by leather-jackets (larvae of *Tipula paludosa*) if attacked in the early stages of growth before the adventitious root system has formed; for early sowing lengthens the period before the formation of the adventitious roots and consequently renders the oats susceptible for a period longer than usual, and so they are more liable to be damaged.

Some discussion of the agricultural practice of **Manuring** as a possible factor in insect control cannot be omitted from a chapter of this nature, since it is a prevalent opinion that manures, and especially artificial manures, are effective in checking certain pests. Wireworms, for example, are said to be affected inimically by the ammonia produced from fresh stable manure, or by the ploughing into the soil of such a green manure crop as charlock. An insecticidal value has been claimed for *calcium cyanamide*, for *basic slag*, *nitrate of soda*, and *Kainit*, in the destruction of surface larvae. *Soot*, which is regarded as a nitrogenous manure, is recommended repeatedly as a deterrent.

In general, however, it is not probable that a fertiliser applied in the usual quantities will have a direct general insecticidal effect. At the same time, it must be admitted that the fertiliser, by altering the chemical composition of the soil, may render the soil conditions either unfavourable or more suitable to insect pests. There is little doubt, for example, that certain manures, especially those containing much organic matter, encourage soil insects. Any good effects resulting apparently from the application of fertilisers to infested crops would seem, however, to be due to their stimulation of the plant to increased growth and consequently greater resistance to the insect pest rather than to any actual insecticidal value.

Perhaps the most important cultural method of all, from the insect control standpoint, is, or ought to be, the method of **harvesting** the crops, and particularly the treatment of straw and the grain. A case in point is afforded by Cotton (1919), who relates that in the season of 1919 the wheat grew so vigorously in the United States that most of the galls formed by the Joint Worm (larvae of *Harmolita* spp.) were high upon the stalk and consequently most of the insects were taken from the field in the straw and not left in the stubble. However, if such straw were used either for packing material, or trampled in the yards by livestock, the adults on emerging would probably fail to find wheat upon which to lay their eggs. There is of course the possibility of the part of the straw containing the gall passing out of the threshing machine with the grain owing

to the weight, so that grain from such infected wheat should always be dressed.

It may be laid down as a general procedure that cereals should be threshed as soon as possible after harvesting, and that the seed product should be stored under insect proof conditions; and if in any way infested by pests should be disinfected as soon as possible.

The following general scheme of methods for controlling wireworms affords a very useful resumé of the various measures comprised in a method of insect control based upon cultural practices.

" The pasture cannot be ploughed too early. It should be eaten short by stock and then ploughed up. Plough with a good strong furrow; use a skim coulter to make sure of burying all with the sod, and use a tail-piece to the mould-board to ensure that the furrow is well broken. Early ploughing with a well-broken furrow induces rapid and more thorough decay of the plants ploughed under, and subjects the wireworm to a long period of starvation before the next crop is sown. Grain stubble should also be ploughed early. When the land is under a root crop, the opportunity should be taken to clean it thoroughly of weeds, as they afford so much winter food for wireworms.

" In spring the chief aim must be to obtain a vigorous young growth of shoots that will be resistant to wireworm and will grow quickly beyond the stage at which they are most easily injured. Such a growth is best secured by having a well-prepared seed bed, by not sowing too early, and by judicious manuring. When there is a likelihood of a crop of lea oats being attacked the application of the following mixture of artificial manures is strongly recommended: 1 cwt. sulphate of ammonia, 3 cwts. superphosphate, 3 cwts. Kainit, per acre."[1]

Finally, it will be understood that if cultural methods of insect control are to be effective, the co-operation of agriculturists over a considerable region is essential. To take an example, deep ploughing in the autumn, if it is to be a satisfactory control measure, must be carried out in every infested field in the district, since insects can often migrate considerable distances. Unless control measures are undertaken on a large scale in this way, it is impossible to obtain anything but a slight temporary relief from any insect pest.

[1] *Journ. Dept. Agric. and Tech. Instruction, Ireland,* xiii. No. 4, 1914.

# CHAPTER XIII

## RESTRICTION OF SPREAD

PREVENTIVE measures against insects cover much of the field of Mechanical Control, for upon the degree of thoroughness with which prevention is carried out depends the extent of future infestation and the consequent necessity for remedial measures. The wide range of measures covered by the term Restriction of Spread is well illustrated by the following epitome of preventive principles laid down by Lefroy (1917), intended primarily to apply to the keeping clean of British orchards, but applicable to Agriculture, Horticulture, or Forestry in general.

These principles are: (1) Clean up rubbish, (2) have no grass, (3) have open fences and clean ditches, (4) remove dead wood, (5) cut out soft shoots, (6) tar pruned surfaces, (7) winter wash, (8) control wild food plants, (9) maintain a summer spraying sequence, (10) grease band, (11) Codling Moth band, (12) collect windfalls.

That is to say, Restrictive Measures fall roughly into five groups:

1. **Destruction of diseased material.**
2. **Collection of the insects themselves.**
3. **Isolation of infested areas.**
4. **Selection of pest-free seeds, plants, or stock.**
5. **Disinfection of infested areas, crops, and stock.**

It is very difficult to make any preventive measure anything like absolute. General principles can be laid down, but their application to any particular problem will always depend very largely upon adaptation to local conditions. Much depends, for example, upon a complete knowledge of the life-history and habits of the pest that is to be prevented, and few insects have been investigated with such thoroughness as to render preventive measures merely a formula to be applied without initiative by the operator.

**Destruction of infected material** is obviously a measure of the utmost importance, since such material is almost always a primary focus of fresh outbreaks. One of the most fertile sources of an insect-epidemic, for example, is the rubbish heap ; the accumulation of bricks and stones, pea-sticks, pulled weed, cut grass, in some corner of the garden ; of manure, thrashing machine refuse, etc., in the farm-yard ; of prunings and dead leaves in the orchard, or the last year's stubble or potato-haulms of arable lands. The rigorous treatment of such rubbish cannot be too strongly emphasised.

Such treatment may consist of burning, pruning of dead wood, etc. ; the burning of stubble is not a desirable, nor is it an adequate measure against insects that infest stubble, and there is also a considerable waste of organic matter, the loss of which may be especially serious in areas which are new, agriculturally speaking. Wolcott (1915) states that in areas where sugar cane is attacked by the Smaller Moth Borer (*Diatraea saccharalis*), the burning of the stubble or " trash " after the cane has been harvested encourages future infestation, since the method kills large numbers of the egg parasite (*Trichogramma minutum*).

The Chinch-bug (*Blissus leucopterus*), the notorious cereal pest of U.S.A., spends the winter in certain grasses : in Kansas, for example, in bunch grass (*Andropogon scoparius*), big blue stem (*Andropogon furcatus*), false red top (*Triplasis purpurea*), and various other shelters.

The destruction of such grasses around the wheat-fields by fire in late autumn or early winter has so far proved to be the cheapest and most practicable method of tackling this intractable pest (Headlee and McColloch, 1913).

Burning is not always practicable ; weeds and wild food plants generally are more conveniently ploughed or delved under than burned. Very many insect pests of fruit or of farm crops not only feed during winter on wild food plants, but hibernate or pupate at the roots of such plants and are thus controlled better by the ploughing under of such plants. The part played by wild food plants in permitting insect pests of cultivated plants to establish themselves is not sufficiently realised. Not only has every " First Class Pest " of such plants originated from allied wild plants, in many cases within the memory of man, but the bulk of insect damage is caused by insects which live normally upon wild plants and attack cultivated plants sporadically. The variety of insect species that may be harboured by one species of wild plant is astonishing. In Great Britain, for example, the hawthorn (*Crataegus*) serves as food plant for the following insect species : Lappet Moth, Brown-Tail, Gold-Tail, Lackey, December Moth,

Figure of Eight Moth, March Moth, Clouded Drab, Ermine Moths (plum and cherry species), Apple Aphis, Woolly Aphis, Mussel Scale, Brown Scale, Magpie Moth, Pear-leaf Blister Moth, Early Moth, Shotborer beetle, Plum-leaf Sawfly, Cherry Fruit Moth, all of these being serious enemies to fruit trees (Lefroy, 1915).

In forestry a general preventive measure against tree-boring insects is the ruthless destruction of the most badly infested trees. In Canada, Swaine (1920) claims that by destroying 75 per cent of infested bark, having selected the most heavily infested trees, 75 per cent of the broods of the Bark Beetle (*Dendroctonus* spp.) can be killed. Where logging is not profitable, the trees are barked and left standing, or are cut down and the bark is burned.

Destruction of infected material is not always advisable, for economic reasons.

Two cases in particular where destruction is out of question may be mentioned: *stable-manure* and *louse-infected clothing.*

Stable manure is a notorious breeding-ground of the House Fly (*Musca domestica*) and the Stable Fly (*Stomoxys calcitrans*), and is from the agricultural point of view a valuable product.

Methods of house-fly control based primarily upon destruction of larvae in stable manure break down economically, unless the suggested treatment of the manure is such as not to impair its fertilisation value.

It is of course a difficult matter to hit upon a method of sterilisation that is larvicidal yet not markedly bactericidal.

Experiments in Great Britain (Saunders, 1916) suggest:

1. Surface dressing of manure with green tar oil, or with neutral blast furnace oil, and soil, at the rate of 1 part of oil to 40 parts of soil; the mixture is spread over the surface of the heap to the depth of one inch, and in forming a fresh heap the ground below is previously oiled.
2. The application of *tetrachlorethane,* 2 oz. to 10 cubic feet of manure.

   Tar oil is preferable, being resistant to rain, whereas tetrachlorethane slowly evaporates.

In U.S.A. extensive experiments by Cook, Hutchison, and Scales (1914, 1915) have been made with a wide range of larvicidal chemicals. By far the most effective, economical, and practicable of the substances tried were *borax* and powdered *hellebore.*

Borax should be applied to the rate of 0·62 pound (or 0·75 pound of *calcined colemanite* in America) per 10 cubic feet

(8 bushels) of manure immediately on its removal from the stable. It is applied particularly round the outer edges of the pile with a flour-sifter or similar fine sieve, and 2 or 3 gallons of water is then sprinkled over the treated manure. Not more than 15 tons per acre of manure so treated should be applied to the field. In fact, if intended for market garden purposes, where large quantities per acre are used, manure is preferable treated with powdered hellebore, which is, however, more expensive, at the rate of $\frac{1}{2}$ pound to 10 gallons of water per 8 bushels of manure.

In France, Roubaud (1915) is opposed to the use of chemicals chiefly on the grounds that they inhibit fermentation and so grant to the fly, which will not oviposit upon fermenting manure, a longer period for oviposition. His suggestion is to use the heat of fermentation of the manure heap. Experiments show that larvae exposed in manure to a temperature of 50 degrees C. and protected from the gaseous products of fermentation die within three minutes ; if in contact with the gases, they die in one minute at a temperature of 57 degrees C., and in four or five seconds at 60 degrees C. These temperatures are those occurring within the manure heap. He suggests a daily forking over of manure during its first three days, so that the majority of the contained larvae fall into the hotter interior parts of the heap and are killed instantly.

The same principle is the basis of the method suggested by Copeman (1916) of destroying Muscid larvae in manure by packing it down very closely.

The simplest treatment of *louse-infested clothing* would be of course destruction by fire, but during the War when enormous quantities of such clothing had to be dealt with as a matter of daily routine, destruction was out of the question, for reasons of economy. The results obtained from much experimental work and from field experience indicate, speaking generally, that for the disinfection of such clothing the only reliable and practicable method is that of sterilisation by heat. In the British Armies, the use of hot-air huts heated by coke braziers gave fairly satisfactory results (Grant and Bacot, 1918). In Serbia, to control the outbreak of typhus and relapsing fever, the British Military Sanitary Mission devised a method of sterilising large quantities of clothing by means of steam. The disinfector was made from a steel van, and an old railway engine was attached in order to transport the van and to produce the steam. Clothes placed in this van for an hour could be saturated with steam, which rapidly evaporated when they were shaken in the air, leaving them dry in a minute or two. A great volume of steam can be produced from the

boiler of a small engine and can be driven into the van at such a pressure as to penetrate large bundles of clothes. The steam, emerging from the boiler under a pressure of four to seven atmospheres, is suddenly reduced to atmospheric pressure on entering the van, and, owing to the heat of condensation produced, a temperature of 212 to 220 degrees F. is attained even in the interior of such bundles.

Such a disinfector with a double van was capable of dealing with 500 kits with 1000 blankets and 500 overcoats every two hours, or 10,000 kits and overcoats and 20,000 blankets every four days (Hunter, 1918).

The German military authorities relied to a large extent on hot-air sterilisation, as carried out by an apparatus termed the *Vondran hot-air apparatus*, consisting of twin disinfection chambers into which a blast of heated air could be introduced by an electric fan through holes in the floor. The articles to be treated are hung upon a framework, so that they become blown out by the blast of hot air and a uniform temperature is attained everywhere. The exposure of clothing for forty-five minutes to temperatures ranging from 178 to 186 degrees F. is effective against lice (*Pediculus* sp.), according to Baerthlein (1916). Experimental tests at Hanover with this apparatus, carried out against pathogenic bacteria, indicated that, after the temperature has reached 159 degrees F., an exposure for ten minutes of garments containing contaminated silk threads in the pockets was sufficient to kill the less resistant bacteria (Glanders bacillus, for example); other varieties, such as *Streptococcus* and *Paratyphus*, required 212 degrees for ten minutes; *Staphylococci* 257 degrees F. for sixty minutes; even this did not affect anthrax (Miessner and Lange, 1917).

A method employed by the United States Public Health Service in dealing with louse-infested clothing is that of placing the garments in a chamber wherein a vacuum of 10-15 inches is created; steam is then introduced until the gauge indicates 20 pounds. A temperature of 259 degrees F. has now been attained. This is maintained for ten minutes to ensure penetration. By again creating a vacuum of 10 inches and maintaining it for ten minutes, the clothes can be completely dried.

**Collection of insect pests,** the second group of preventive measures, may be carried out by *hand-picking*, by *mechanical-collecting*, by *farm livestock*, or by *trapping*.

Hand-picking is always laborious and costly, and can only be recommended where a severe infestation is uncontrollable by any other method and where labour is cheap. The larvae of the Large Cabbage White Butterfly (*Pieris brassicae*) and

the Small White (*Pieris rapae*) are conspicuous, uncontrollable by such insecticides as can be applied to cabbages, and not readily attacked by predatory insects and birds. Hand-picking is the only method that can be advocated, and even this is only applicable on a small scale. The eggs of the *P. brassicae*, being laid in clusters on the underside of the leaves, can be hand-picked even more readily than the larvae, but hand-picking of eggs is useless against *P. rapae*, whose eggs are laid singly.

Hand-picking, or a semi-mechanical form of it, has been tried on an experimental scale in the control of Cotton Boll Weevil in Louisiana, U.S.A. The method of collection used was the ordinary system of bag and hoop shaking, the plants being shaken into a sack held open by a hoop sewn in the mouth. Results obtained did not justify recommendation of this method for large scale work; the number of weevils caught was considerable, but the number missed was amply sufficient to cause severe damage; further, this bag-picker was so injurious to the plants that it actually reduced the crop considerably (Coad and McGhee, 1917).

The systematic catching by hand of mosquitoes is a measure that has been tried with considerable success in habitations in the Panama Canal Zone. The work is carried out by trained negroes each provided with a large test tube containing a pad soaked in chloroform. According to Dunn (1919), between the 1st February 1916 and 31st January 1917, 391,019 mosquitoes were caught in this manner, of which number 251,332 belonged to the species *Taeniorhynchus titillans*, a mosquito somewhat difficult to control by the usual anti-larval methods. Not only has the method shown itself to be economical, practicable, and successful, but it is also useful in acting as an index to breeding-places. Should the Yellow Fever Mosquito (*Aedes calopus*), for example, occur in a catch, an adjacent breeding-ground is thereby indicated, and measures can be taken to locate it and abolish it.

If an overwhelming infestation by an insect pest has to be dealt with, some form of mechanical collecting machine will be found useful. Its construction will depend very largely upon the ingenuity of the operator. However, a standard contrivance known as a *hopperdozer* is now widely used for collecting young locusts or hoppers. It consists of a light framework upon runners; watertight trays are fitted into the base of the machine and contain water and coal-tar oil; raised canvas sheets complete the sides and back of the machine (Fig. 12).

A simple type of hopperdozer is that described by Webster

(1915). A sheet of iron is taken, ten to twelve feet long and twenty-six inches wide. One long edge is turned up to a depth of two inches, the other long edge turned up to a depth of twelve inches, thus making a shallow pan with a front two inches high, a back twelve inches high, and a width of twelve inches. Ends are soldered in. Runners of old waggon tyre are placed at each end and one in the middle. The latter one is turned over at the front (low) and back (high) edges of the pan in order to strengthen it at these points. All three runners are attached to the pan by rivets and solder. The pan contains water having a surface film of paraffin.

A hopperdozer is drawn over the ground by a horse, and as it progresses over the field the young locusts, or hoppers, leap up, strike the canvas sheets and fall into the trays, where they succumb to the solution.

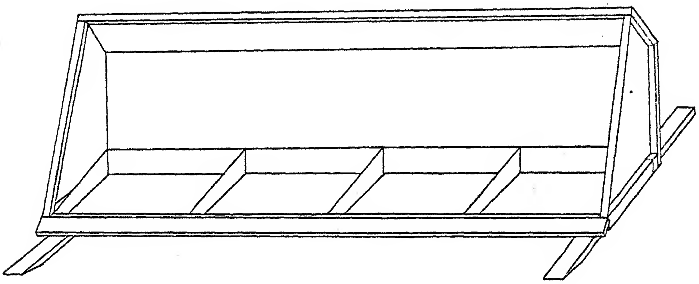


FIG. 12.—Hopperdozer. (After Criddle.)

Another method of insect collection is by the use of live-stock; pigs and poultry may be allowed to run over the stubble after harvest with the object of eradicating soil insects. Fowls especially will range a field after ploughing and pick up great numbers of insects exposed on the surface or in the top layers of soil. There is a certain amount of prejudice amongst farmers against allowing poultry to run on agricultural land, except within the limits of the usual fowl runs, but there is no doubt that the running of poultry over stubble and through orchards is a very effective measure against such insects as hibernate or pass part of their life-history in soil. Theobald (1917) asserts that trees in grass-grown and cultivated orchards to which fowls have access are much healthier than trees in closed orchards. In spring and summer they collect the larvae of the Winter Moth (*Cheimatobia brumata*) that come down to the ground to pupate and also seize the wingless females of this moth as they emerge from the soil in autumn and

winter, thus lessening the risk of an epidemic in the following year.

Amongst other insect species in British orchards, the following are known to be destroyed by fowls: larvae of the Codling Moth (*Cydia pomonella*), of the Pear and Cherry Sawfly (*Eriocampa limacina*), of various leaf-rolling Tortricids, of the Lackey Moth (*Malacosoma neustria*), of the Pear Midge (*Diplosis pyrivora*), the cocoons of ants (*Myrmica* and *Lasius* spp.), the Apple-Blossom Weevil (*Anthonomus pomorum*), the Raspberry Weevil (*Otiorhynchus picipes*), and various Aphides. On arable land they also destroy wireworms (Elaterid larvae), surface caterpillars (Noctuid larvae), and leather-jackets (Tipulid larvae).

Theobald considers that care in the selection of poultry suitable for orchards should be taken, since the lighter breeds, although more active in finding insects than heavy poultry, are liable to fly up into the trees and attack the fruit. When only standard trees are grown this difficulty does not present itself, but orchards with bush fruits and half-standard trees should not be made accessible to young poultry, at any rate until the fruit is half-grown.

It has been suggested that an effective measure against insects which are found in herbage may be employed by allowing the land to be grazed by live-stock.

Miller (1916) considers, for example, that the Geometrid larva (*Xanthorhoe praefectata*), which damages flax in New Zealand, can be checked by allowing sheep to roam over the ground, since they eat the undergrowth in which the larvae shelter during the daytime.

Gossard (1916) in U.S.A. asserts that autumn grazing will effectively reduce the Clover-Leaf-Tier (*Ancylis anguli traxiana*), an insect which binds together one or more petioles of the clover with a silken thread and retires within the cell formed in this way.

In certain areas of U.S.A. overrun by the Rocky Mountain Spotted Fever Tick (*Dermatocentor venustus*), such as Bitter Root Valley, Montana, experiments have been carried out by the U.S. Department of Agriculture and the United States Public Health Service in the collection of ticks by grazing sheep over infested areas.

The Bitter Root Valley is narrow and limited by high, precipitous mountains. The ticks and the small rodents which serve as hosts to them are found chiefly in the foot-hills and along the lower slopes of the mountains. Higher up, there are few ticks, except in the haunts of the Rocky Mountain Goat, and few small animals to serve as hosts. A flock of

sheep started in the foot-hills between two canyons and allowed to graze for a week would pick up practically all the ticks in that locality and destroy perhaps 90 per cent of them. Then if the sheep were shifted into the mountains to a site above the tick-zone the engorged ticks which drop from the animal to the ground after ten days' attachment in order to oviposit would drop upon ground where newly hatched larvae would find few suitable hosts.

The method in fact depends for success upon the removal of sheep, within ten days from commencing to graze, to a site above the tick-zone. Success depends also upon the carrying out of accompanying measures, such as removal of undergrowth, destruction of wild animals, particularly the Ground Squirrel (*Citellus columbianus*), the Pine Squirrel (*Sciurus hudsonicus richardsonii*), and the Chipmunk (*Eutanias luteiventris*), the destruction of the ticks themselves (principally by lanolin in the wool), and upon the scale of the operations carried out. Experiments with 1500 sheep were estimated to result in the destruction of 25,000 adult ticks in one season, so that in a tick area favourable to sheep-grazing the method promises great success (Wood, 1913; Fricks, 1915; Cooley, 1915).

Even these few examples of collecting methods will indicate that this aspect of insect restriction is not by any means the least important among control measures, and the further question of collecting insects by *trapping* has developed into such an important line of insect control that it can only be discussed adequately in a chapter devoted solely to its consideration.

**Isolation of clean areas and of infested areas** is a measure applicable to a wide range of conditions, the area to be isolated being anything in extent between a vast tract and a portion of a single plant. Consequently only the most general methods of carrying out this measure can be indicated.

Isolation, generally speaking, is effected by the use of trenches against wingless insects, by the use of dusted or sprayed barriers of vegetation, or by actual mechanical obstacles which protect susceptible portions of the plant or animal.

Thus where an insect pest is wingless and migrates by moving along the surface of the ground from field to field, it may be prevented from extending its area by the use of a clear space or a trench around the focus of infection. Phillips (1920) claims that the Joint Worm (*Harmolita* spp.), a cereal pest of U.S.A., can be restrained by leaving forty yards clear space between an infested area of newly sown wheat, since the wingless generation cannot cross this space.

With such pests as surface larvae, trenches around both uninfested and infested fields are usually effective, since migrating larvae are caught in such barriers.

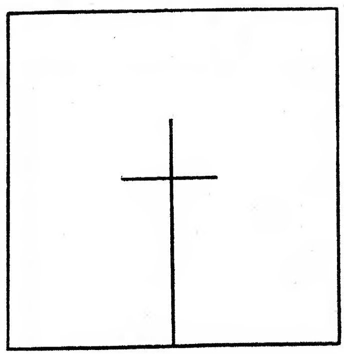
Barriers to prevent ants ascending trees, table-legs, etc., can be provided by the use of tape smeared with a mixture of one part corrosive sublimate and six parts Tanglefoot, or better still of 1 part flowers of sulphur and 6 parts of Tanglefoot. The "ant-tape" of commerce, prepared by soaking strips of cotton cloth in a saturated aqueous solution of corrosive sublimate, is useless out of doors. Horton (1916) recommends the following formula: corrosive sublimate 20 grams, dissolved in 60 c.c. ethyl alcohol, and 31 grams of orange shellac added to the solution. This mixture can be painted upon the legs of tables, beehives, etc., it dries perfectly hard in a few minutes, is absolutely waterproof, and will remain for more than a year, on wood.

To restrict the spread of the Green Japanese Beetle (*Popillia japonica*), a serious pest of ornamental plants in the United States, an attempt has been made to maintain an impassable barrier of dusted or sprayed foliage about one mile wide around the infested area. This region in New Jersey State was estimated by Howard (1920) to cover fifty square miles In spite of these measures, it would seem that the pest is gradually extending its range each year, and that there is little hope of preventing its spread. One of the practical difficulties that occurred was the question of avoiding sprays or dusts that might be poisonous to cattle, a factor that almost restricted the possible insecticides to lime-sulphur preparations.

The value of various devices to protect certain portions of plants has been recognised for some time. A good example is afforded by the tarred disc method of protecting cabbages or cauliflowers from the attack of the Cabbage Root Fly (*Phorbia brassicae*). This Anthomylid fly lays its eggs in the soil close to the plant and at the point where the plant emerges from the soil, and the resulting larvae burrow downwards in the root of the cabbage. Seedling plants succumb to this attack, but older plants can withstand the drain upon their resources. The protection method consists in placing a piece of tarred felt, two inches square (Fig. 13), around the stem of the young plant and pressing this disc close to the ground so as to prevent the female fly from reaching that portion of the plant stem which is at the soil level (Wadsworth, 1917). No advantage would seem to be derivable from coating this disc with a sticky substance, since the resulting coating of dust soon destroys the adhesive quality.

*a*

*b*



*c*

FIG. 13.—*a*. Appearance of field of cauliflowers, Northenden, Cheshire, England, on July 4, 1916. First and third rows from the left have been protected by tarred discs; other rows were unprotected. *b*. Brussels sprout plant with disc in position. *c*. Diagram of disc, four-fifths actual size.

N

The main objections that have been brought against this method are:

1. Diametrical growth of the stem is restricted by the slit. This can be overcome by having a circular or star-shaped perforation in the centre of the disc, a slit running from this to one edge.
2. That the disc "cockles," the edges of the slit come apart and the fly can creep under. The remedy against this is double disking, the use of two discs, one placed diagonally upon the other; or the use of a disc with flanges like the lid of a cardboard box has been suggested and patented.
3. That in low-lying lands, where the heat acts on the subsoil and causes much diffusion of water vapour from it such vapour condenses beneath the disc and causes a plant condition known as wilt. This is a serious objection, and under such conditions probably the use of corrosive sublimate, 1 : 1600 of water, is preferable, one teaspoonful per plant being applied once weekly during the flight period of the fly (the month of May in Great Britain).

The same principle has been suggested for controlling the Peach Borer (*Aegeria exitiosa*) of U.S.A. This insect oviposits on the crown of the tree, and the larvae hatching from eggs laid on the trunk and branches migrate downwards, and commence boring when below soil level. To prevent this, Blakeslee (1915) describes a device consisting of a tarred felt mat, sixteen inches in diameter, with a central hole corresponding to the diameter of the tree, and a slot from the hole to the outer edge, as in the cabbage disc, permitting the mat to be slipped round the trunk. The soil is first moulded round the tree, the protector adjusted to the mould, its slit edges glued together, and the whole mat sealed to the tree with a sticky material. As a consequence the migrating larva cannot reach the soil without crawling away from the tree beyond the edge of the mat. When the mat was placed experimentally at the crown of the tree, the larvae did not try to bore into the tree above the mat. Care must be taken, of course, in the selection of a sealing material non-injurious to the tree.

Mention may be made here of the old device of protecting ripening fruit by covering them with paper bags. Soyer (1915) describes an improvement upon this method, namely the substitution of cylindrical boxes of wire gauze for paper bags, the advantages thus obtainable being greater durability, ventilation, and more perfect ripening.

Brief reference may also be made to the technique of screening habitations against biting flies. In mosquito-infested localities, all houses should have doors, windows, ventilators, fireplaces, covered with metallic gauze. There are certain mechanical difficulties connected with the fixing of such gauze over doors and windows, owing to the frames of such openings tending to warp; a screened verandah surrounding the house would seem to be preferable, the higher initial cost being set off somewhat by the less expense of upkeep. If, however, the door has to be screened, the metallic gauze should be guarded by wide-meshed wire netting. The frame should be stiffened by a diagonal steel rod, which should be divided in the middle, the cut ends being fitted into a sleeve so that the tension can be adjusted (Orenstein, 1914). In a severely infested district, the outer doors should be reached through a mosquito-proof antechamber.

The material of the gauze is of importance. Iron is not suitable owing to the rapidity with which it oxidises and corrodes in a damp climate. Experience at Panama suggests that the gauze used should contain 90 per cent of copper and not more than 5 per cent of iron. For protecting the port-holes of ships, gauze made of oxidised phosphor-bronze is satisfactory. As a general rule the gauze should contain 18 meshes to the inch, and should be held in place by copper tacks.

To pass to the consideration of other methods of preventing insect ravages, **the selection of clean seeds and plants** is of primary importance. The use of good seed cannot be too strongly emphasised, not only because it will give a higher percentage germination, but also because, being clean, it will be free from insect pests. No infected seed should be sown until properly disinfected by the methods described under Crop Storage, unless such infestation is slight and the infesting insect difficult to kill, when much can be done by quick-acting manures.

**Disinfection,** in its broadest sense, can hardly be laid down as a definite method of restrictive control, representing as it does the employment of many and varied methods of control. Applied to a large area, such as the Gipsy-Moth-ridden forest regions of U.S.A. or a mosquito-infested tropical town with its swampy environs, the term " disinfection " may be almost as comprehensive as the term " insect control " itself. Applied to an individual plant or animal the term may be merely synonymous with sterilisation.

In the narrow sense, however, we imply by disinfection the elimination by chemical or physical methods of some pest infesting :

(*a*) a natural region of country ;
(*b*) a cultivated area, field, allotment, garden plot, or hotbed ;
(*c*) crops, seedlings, seed ;
(*d*) live stock.

As an example of the general principles involved in the disinfection of a natural region infested with an insect pest, we may consider the treatment of a mosquito-infested area. The literature upon this question is enormous, but a general summary of anti-mosquito methods has been given recently by Metz (1919).

All mosquitoes, so far as is known, undergo their larval period in water, but they vary greatly as to the kind of aquatic environment they prefer. Some species require running pure aerated water; others prefer the stagnant waters of a swamp, rice-fields, ponds, and puddles; others breed in artificial containers such as cisterns or water-butts, the holes made by land-crabs, the hoofprints of mules; some even in salt or brackish water, in sewage or the effluent from chemical works.

Mosquito control measures, therefore, being aimed primarily at elimination of the larval stage, consist of :

1. *Drainage*, where water can be so disposed of.
2. *Use of larvicides*, where water cannot be drained and is not required for domestic or commercial use.
3. *Oiling*, where water is thus required, or where conditions militate against the use of larvicides.

Drainage problems occur in connection with lakes, swamps, ponds, and their solution varies according to the source of the water. Rainwater-ponds and swamps are usually dealt with by the provision of V-shaped ditches, preferably lined with concrete to carry off surplus water left after the main flood waters have passed. If, however, the pond or swamp be a basin in the channel of a sluggish stream, the problem is more difficult, since the water supply is continuous and fluctuating; the usual treatment is to deepen the stream below the basin so as to increase the outflow.

The control of mosquito-breeding in large ponds and lakes is best accomplished by the encouragement of fish. This entails a sufficient stock of fish and the clearance of vegetation and rubbish from the surface and margins. It must be noted, however, that the use of such fish is very limited. Unless care be taken to stock the pond with pure fry only, continual replenishment of the stock will be necessary, as the small fish themselves are devoured by larger predatory fish.

Swamps formed by seepage outcrops, by water oozing out

from a hillside, for example, can be drained by ditches dug at right angles to the flow of the seepage water—that is, across the exposed end of the water-table. Such ditches connect with main ditches running down the hillside parallel to the seepage flow. Or wells can be sunk through relatively impervious soil into water-bearing sand or gravel, but this is a method advisable only when surface-drainage measures are difficult or expensive.

*Larvicides*—that is to say, chemicals toxic to the larva—are as a rule too expensive for large-scale employment unless chemical by-products are obtainable, and they cannot be used where there is any risk of poisoning animals or destroying fish. Very many substances are available for this purpose. Sodium cyanide at the rate of 1 : 100,000 parts of water is frequently recommended. Very good results have been obtained by the use of crude cresol added to the oil used in oiling operations; 1 part per 1,000,000 of water is effective. A cresol larvicide much used in the Panama Canal zone is prepared by boiling together *resin, soda,* and *crude carbolic acid* in the proportions of 5 : 1 : 40 by weight. The resulting product is a black liquid resin soap, an emulsion of which in water, 1 part in 5000, should kill an Anopheline larva in ten minutes. This type of larvicide has certain objections: it does not emulsify in brackish water, and the presence of decaying vegetation seems to affect its efficacy. Further, it is fatal to fish.

Where there is no access of fresh water, an emulsion that contains nearly all the light oil that the emulsifying agent can carry and has no unnecessary water may be used in the proportion of 1 in 32,000. The following formulae are given by Kirk (1918):

1. Soft soap, 100 parts; light oil, 440 parts; water, 100 parts; caustic soda, 80 parts; the light oil being added after the other substances have been heated together to 212 degrees F.: the result is a thick jelly that may be liquefied by dilution with water.
2. Soft soap, 20 parts; light oil, 50 parts: giving a thick jelly-like soap.
3. Castor-oil, 50 parts; caustic soda (sat. solution of 98 per cent caustic soda), 15 parts; water, 20 parts; light oil, 170 parts; the castor-oil and caustic soda being first boiled together to make an even yellow-green soap, to which the light oil may then be added: the resulting emulsion is a clear liquid that keeps well.

It must be noted that mosquitoes have been frequently

observed in the larval condition in water so polluted with chemical waste products as to be poisonous to all other animal life.

Metz (1918) has described a swamp in Alabama whose waters were polluted with the refuse from a sulphuric-acid factory, with nitre cake in particular, yet were literally swarming with larvae of *Anopheles crucians*. The larvae were feeding upon minute particles of disintegrated plant tissue resulting from chemical action upon vegetation.

Feytaud (1919) found larvae of *Anopheles bifurcatus* and *Anopheles maculipennis* living in water heavily impregnated with refuse from a melinite factory; and experiments to ascertain the power of resistance of larvae of these species to picric acid in water showed that half-grown larvae lived for a quarter of an hour in a 50 per cent solution, five hours in a 4 per cent solution, four to five days in a 1 per cent solution, a week in 0·25 per cent solution, and in a solution of 1 part in 600 were able to complete their metamorphosis. Possibly the resistance of such larvae is greater still when accustomed to the medium from the moment of hatching.

*Oiling*, in principle, consists in the application of a thin film of mineral oil to the surface of the water. The exact toxic action of this operation is disputed, and has been previously discussed. No definite type of oil can be recommended above all others. Ordinary kerosene is effective, spreads rapidly and forms a very thin film; but it evaporates quickly, and the film is difficult to see. It is preferably mixed with crude oil in proportions varying from 3 : 1 to 1 : 3. The most satisfactory mixture is nearly black in colour and slightly thicker than kerosene (Metz, 1919). On stagnant water such a mixture can be applied as a spray; where there is a current, various devices are used—drip cans, bags of oil-soaked waste, for example. Small accumulations of water, such as hoofprints, can be effectively and quickly treated with oil-soaked sawdust. In the Panama zone, crude oil of asphaltum is extensively used—half a million gallons per annum, according to one authority; it is cheap, but its poor spreading qualities would make it unsuitable to cooler climates.

Vegetable oils give more permanent films than do mineral oils, but do not spread as readily. A mixture of 2 parts castor-oil to 100 of kerosene, however, spreads even better than kerosene, and is more permanent. Two ounces of kerosene will cover only an area of five square yards diameter, whereas the same quantity plus 1 per cent of castor-oil will form a film thirty yards in diameter within fifteen minutes (Leak, 1915). The film is not readily broken up by wind, or by reeds, nor

is it affected by dust on the water, or by presence of grease or soaps.

Such oiling should be repeated every ten or eighteen days.

It must be pointed out that the prevalent opinion, based, generally speaking, upon Réamur's account of the life-cycle of *Culex pipiens*, that in temperate regions all mosquitoes hibernate as adult females, and that swamps and stagnant waters produce mosquitoes throughout the warm months, is erroneous. In Germany, for example, of twenty species only five hibernate as adults. The majority of North American mosquitoes, too, hibernate in the egg stage; the larvae occur in the spring, and the larval period is short. The female imagoes are long-lived, and endure throughout the summer. Such facts concerning the exact period of the year when larvae occur in the water are of great importance when oiling measures have to be carried out.

Many cases, of course, occur in connection with mosquito control where drainage and oiling methods cannot be readily carried out. Rapidly-flowing hill streams, for example, are almost impossible to deal with in this way. In many such mountain streams, however, the stream disappears after some distance owing to the accumulation of loose stones and rubble; in the pools between the running water and the dry bed are the breeding-places of the mosquitoes. In such streams, satisfactory results are obtainable by erecting dams to allow the accumulation of sufficient water to flush the stream bed from time to time. Such flushing carries the larvae down to the dry stones, where they perish.

Rice-fields, again, afford a difficult problem in mosquito elimination. For the successful cultivation of rice, the fields have to be flooded to a depth of four to five inches during the hot season, and the water allowed to lie stagnant for about five months. That is to say, the optimum conditions for the production of rice and for the breeding of Anopheline mosquitoes unfortunately coincide. Rice cultivation, however, does not necessarily encourage malaria; in fact, many rice-growing areas are remarkably free from malaria. The reason, of course, is that mosquitoes are singularly restricted in their choice of suitable breeding-grounds; many species which are notorious carriers of malaria will not breed in such areas of water; many that do breed in paddy-fields have never been proved to carry the disease. Still, there is no doubt that the introduction of rice cultivation will provoke a large increase in the number of mosquitoes, and therefore in many rice-growing countries considerable controversy is taking place as to whether the

growing of rice should or should not be prohibited in the vicinity of towns.

The control of such mosquitoes is very difficult. The usual larvicides are detrimental to growing rice. Fish are not successful, as the water is usually too shallow for larvicidal species. Dragon-fly larvae, even in the presence of an abundant supply of mosquito larvae and pupae, apparently prefer cannibalism. In British Guiana a system of alternately flooding the rice-fields and then rapidly drawing off the water is said to keep mosquitoes in check; and the draining away of the water for forty-eight hours once a fortnight has been recommended as a remedial measure by several authorities, but this measure adds greatly to the cost of cultivation. It must be pointed out that the overflow pools of surplus water on the edges of the fields, varying in size from small pools to vast water-soaked bogs, afford even better breeding-places than the paddy-fields themselves; they are entirely unnecessary, and could be eliminated by intelligent construction of irrigation ditches and careful use of water (Freeborn, 1917).

Another example where the usual measures are inapplicable is afforded by the case of a water surface covered by vegetation. In the Canal zone of Panama, for example, the construction of the great artificial Gatun Lake, covering an area of more than 150 square miles, has resulted in prominent changes in the flora and fauna. In particular, the Water-lettuce (*Pistia stratiotes*) has spread so greatly that large floating islands of several miles in diameter have been formed. This plant is associated with a species of mosquito termed *Taeniorhynchus* (*Mansonia*) *titillans*, which lays its eggs in masses attached to the under-side of a *Pistia* leaf. The newly-emerged larvae descend into the mass of rootlets, pierce the thin outer skin of one by means of the respiratory siphon, and remain thus attached to the plant, obtaining the necessary oxygen from it. This habit is favourable in many ways; the larvae are protected from solar heat and from aquatic enemies, and owing to the presence of oxygen given off by the plant are relieved from the necessity of surface breathing and so are uncontrollable by oiling measures. Fortunately, this mosquito has not been proved to be a carrier of any disease of man and animals; but should it prove to be so, the eradication of the water plant will have to be undertaken. Probably arsenical sprays would readily destroy such vegetation.

**The disinfection of cultivated areas** will differ as regards methods and technique according to the extent of the area to be treated and the object in view. General sterilisation of the surface soil, for example, against insect larvae, Nematode

worms, or fungi, may be the object aimed at, and a variety of sterilisation agents are available—steam heat, cold water submersion, and soil chemicals.

The use of *steam* as a soil-sterilising agent has given promising results, but has scarcely passed beyond the experimental stage. The apparatus made use of will of course vary somewhat according to the local conditions, but most types comprise a portable boiler capable of producing steam under a moderate pressure. In conjunction with this a rectangular box is generally used, so constructed that one side is open and can be closely applied to the ground. Steam is admitted to the box through a connecting flexible hose from the boiler, and in this way the surface of the ground under the box is subjected to steam heating. The box is then moved and a fresh portion of soil treated. As would seem obvious, the method is not entirely satisfactory, since the steam does not penetrate to much depth in the soil. Somewhat more thorough treatment may be carried out by the use of a "steam rake"—that is to say, a rake with hollow stem and prongs, so arranged that holes at intervals in the prongs permit of the escape of the steam. The stem of the rake is connected up to the boiler and then the steam-rake is dragged through the soil in the usual manner. In this way the soil can be disinfected effectively to a depth of several inches. So far, however, it must be admitted that this method has not progressed very much beyond the experimental stage, owing to the mechanical difficulty of making a portable boiler sufficiently capacious yet sufficiently light. Further, the method is certainly costly, and may prove on this account to be economically practicable only in connection with market gardens.

The *flooding* or *submersion* of infested fields is one of the commonest ways of using cold water against insects, since such flooding tends to asphyxiate insects below the soil surface. The period of submersion may vary between two and sixty days, according to the nature of the soil treated and the type of pest to be destroyed, but it is essential that the soil should only be slightly permeable, that the ground should be fairly level, and that a water supply of 5000 to 25,000 gallons per acre should be available. The ground should be, in fact, thoroughly saturated if any success is to be expected. The cost of the operation depends very largely upon the ease with which water can be obtained.

It may be noted that flooding measures have an exhausting effect upon the soil, and that heavy manuring will be required subsequently. Even in France, where flooding of vineyards is a recognised method of fighting the Vine-root Aphis

(*Phylloxera*), the opinion seems to be gaining ground that the disadvantages of submersion outweigh the benefits, and that the use of soil-insecticides, such as *carbon bisulphide*, can with advantage replace this method of control.

Another example of the practical application of the submersion method is afforded by the minute fly (*Psychoda alternata*) breeding in the Sprinkling-Sewage-Filters in North-Eastern U.S.A. Headlee (1919) suggests, as an effective measure of controlling this fly, the submergence of the filters under water for twenty-four hours once every ten days. He claims a 100 per cent destruction of larvae and pupae.

*Soil insecticides* are not usually very successful for general application, although a large number of various chemicals have been recommended and experimented with; in particular, *lime, coal-tar products* (gas-lime, soot, naphthalene, toluene, benzene, ammonia), *carbon bisulphide, sodium cyanide, corrosive sublimate, paradichlorbenzene, potassium sulphocarbonate,* etc.

*Naphthalene* is frequently recommended, the usual amount per acre being 2 cwt. Soot and gas-lime depend for efficacy upon the slight percentage of coal-tar products in them.

*Carbon bisulphide* is a soil disinfectant much used in France, in quantities varying between 176 lbs. and 3344 lbs. per acre. The general procedure of application has been fully described by Rolet (1914), by Hinds (1918), by Vermorel and Crolas, and by Bourcart (1912).

This substance is only slightly toxic to plants—it is asserted, in fact, that as much as 1 ton per acre can be applied to soil without danger to growing plants; it is certainly highly toxic to insects. Its use, however, from an agricultural standpoint, is limited by the expense, but the horticulturist, particularly the cultivator of flowers and early vegetables, is not so circumscribed. In practice, measured doses of the chemical are inserted into holes made in the soil, so that the vapour will spread through a certain area of soil. In soils, 1 oz., at a depth of eight inches, per square yard is the usual dosage; in a more compact soil 1¼ oz. is advisable. For particular pests, holes may be deeper and doses larger. Thus against *Phylloxera* French vine-growers use ½ to 2 oz. per square yard at a depth of twelve to sixteen inches, the holes being sixteen inches from the base of the vine; against eelworms, 6 to 10 oz. per square yard; against chafer larvae, 7 oz. per square yard.

In the case of valuable crops severely attacked, French horticulturists use large doses, even to a maximum of twenty-five holes per square yard, each hole taking one-third of an ounce; this latter dosage is recommended against Mole-crickets (*Gryllotalpa*) attacking carnations in boxes.

When unplanted soil is to be treated, spring or autumn, prior to sowing or planting, is the best time; the soil should not be too damp, dry weather being an advantage; the number of holes per square yard will depend upon the nature of the soil, five per square yard being the average.

Planting or sowing should be deferred until a fortnight after the soil has been treated.

When soil already planted has to be treated, the holes should not be made too near the roots of the plant; with cabbages, for example, not nearer than four inches.

In a garden, the requisite holes can be made with a stick and the chemical manipulated with a teaspoon. For large-scale work, however, an injection apparatus such as Gastine's injector (Pal Injecteur), or even a kind of plough, is required. The Pal Injecteur consists of a zinc or copper cylinder holding about three kilogrammes of chemical, terminating in a long hollow

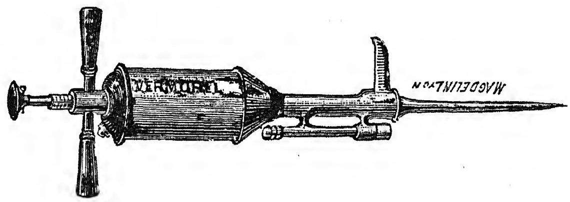


FIG. 14.—Pal Injecteur Excelsior.

spike of cast iron with a conical extremity. Two handles are provided for holding the apparatus in position, and with the aid of an attached pedal the hollow spike is driven to the required depth in the soil. Inside the instrument is a pump fitted with a piston. On depressing the rod of the piston, which projects above the handles, a valve opens and a measured dose of carbon bisulphide is projected into the soil through an aperture at the end of the hollow tube. The hole in the soil is filled immediately after the dose has been introduced.

Owing to the difficulty of forcing the tubular portion of the injector into hard ground, the Pal Injecteur Excelsior has been introduced; the valve is placed in a separate lateral tube, and the hollow tube itself can be made more slender and of steel, so as to penetrate the soil more easily (Fig. 14).

The *Traction injector* is made in several designs (Vermorel and Crolas), but the general principle is the same. There is a plough frame drawn by a horse or ox, fitted with a special share. The main wheel of the plough in turning actuates a

small pump which draws a measured quantity of chemical from a tank fixed on the beam of the plough, and then projects the liquid just behind the hollow formed by the share in cutting through the ground.

The chief objection to all these traction-machines is that the insecticide is not placed deeply enough. Carbon bisulphide is not fully effective unless placed deeper than eight inches, but this is difficult to accomplish in very stiff soils.

Mention may be made of the soil insecticide apparatus employed in U.S.A. against the larvae of the Green Japanese Beetle (*Popillia japonica*) (Davis, 1920), and consisting of a 600-gallon tank drawn by a caterpillar-tractor. The insecticide flows by gravity through a 3-inch pipe having $\frac{3}{8}$-inch holes forty-eight to the foot, the flow being regulated by a gate valve operated by the tractor driver. The usual dosage employed is 165 lbs. of sodium cyanide dissolved in 1200 gallons of water per acre, and each tank will cover one acre per day.

The use of sodium cyanide, however, whilst probably satisfactory for treating masses of loose, porous soil, especially those containing little clay, and for seed beds and potting soil, is too expensive for large areas, particularly when the soil contains much clay or wet sand (De Ong, 1917).

Another substance, *potassium sulphocarbonate,* whilst very effective, is limited in applicability, owing to its cost, to vineyards or to horticultural work. It is produced commercially as a dark red solution, containing 14 to 16 per cent of sulphide and 18 to 20 per cent potash ; in the soil it slowly decomposes into carbon bisulphide and sulphuretted hydrogen, both insecticidal, and the residue, potassium carbonate, has considerable manurial value. It has the advantage over carbon bisulphide of acting more slowly and for a longer time, and of impregnating the soil more thoroughly. It is readily applied from an ordinary watering-can as a 1 to 2 per cent solution, flowers or foliage not being injured by contact with the liquid (Molinas, 1914).

If the aim of a soil sterilisation operation be primarily the protection or treatment of soil around roots of plants, the use of *corrosive sublimate* is frequently recommended. Against Cabbage-root Maggot (*Chortophila brassicae*) or Onion Maggot (*Phorbia cepetorum*) the substance is used at a strength of 1 : 1600 of water, and applied at weekly intervals during the flight period.

The object aimed at may not be general soil-sterilisation so much as treatment of ant-nests, mole-runs, or rat-holes, usually effected by applications of lethal gases. Thus colonies

of ants may be destroyed by pouring one to three ounces of liquid carbon bisulphide into the opening of the nest and covering with an inverted iron tub for five to six hours. Frequently, however, the liquid is so quickly absorbed by the soil that the fumes are liberated too slowly to be effective. Better results are obtainable by forcing air through carbon bisulphide in a generator and conducting the mixed air and chemical vapour through a tube into the galleries of the nest.

Sterilisation of plants is effected by fumigation in closed houses as described in Chapter XIV., by hot-water spraying, by cold-water spraying, and by solar heat.

*Hot-water spraying* has been tried on a large scale, chiefly in the vineyards of Southern France against Vine Moths (*Clysia ambiguella* and *Polychrosis botrana*). Salomon (1915) has described large-scale experiments with this method, using a Moratori constant-jet-sprayer of ten litres capacity in conjunction with a Vermorel-Pyralis boiler. When the shade temperature was 75 degrees F., the hot water was at 162 degrees F. when placed in the sprayer. The jet of hot water at first issued at 150 degrees F., but fell to 136 degrees F. in the fifteen minutes required to exhaust the container, but in this time forty-five stocks each carrying fifteen to eighteen bunches were treated. Hot water at 136 to 150 degrees F. kills all the unprotected larvae and eggs, but several applications would be required to give a 100 per cent mortality.

The vines can be subjected to such hot-water treatment at any time during the three weeks that elapse between the time of oviposition of the moth and the time when the larvae hatch out and shelter within the damaged plant, so that hot-water treatment has a distinct advantage over the use of chemicals, which can be usefully employed only for a period of about five days. If hatching be spread out over three or four weeks, one or two applications of hot water will give theoretically complete control.

In conjunction with hot-water spraying, cupric sprays have been recommended. Semichon (1915) advises that in filling a knapsack sprayer one-third of its capacity should be filled with treble-strength cold cupric solution, and then filled up with boiling water, the mixture being well stirred. The fluid should be used immediately after preparation. Ravaz (1915), criticising such a procedure, points out the possibility of the cupric salts being decomposed or precipitated in the hot spray, and the consequent failure of hot water to increase the effectiveness of a cupric spray.

The great practical difficulty that attends the use of hot-

water spraying methods is of course that of keeping the spray solution at a constant temperature.

Not only is there a gradual decline in temperature from the moment the jet of water leaves the boiler or syringe until it reaches the plant, but also there will be, unless the boiler is continually heated, a gradual cooling of the mass of hot water in the container. This practical difficulty, added to a well-marked divergence of opinion as to the effective temperature necessary to destroy the insects without injury to the plant, has led to considerable criticism of hot-water spraying, especially as applied to vine pests.

Thus it is asserted by Topi (1916) that a temperature of 150 degrees F. will scorch the vine foliage yet fail to destroy the eggs of the Vine Moth. Chauvigne (1915), who has duplicated Semichon's experiments, is of the opinion that the minimum effective temperature of 130 degrees F. required cannot be maintained when a fair-sized area is under treatment.

*Cold-water spraying* has been employed successfully in Queensland, Australia, against the Woolly Aphis (*Eriosoma lanigera*) of apple trees. The trees are sprayed four times during the summer—that is, during the period December to March. The operation is carried out usually before the trees are sprayed with lead arsenate (against the Codling Moth), and after each spraying the soil beneath the trees is churned up with water so as to bury any Aphides that happened to be washed from the tree.

Yothers (1915) claims similar success in U.S.A. against the Mealy Bug (*Dactylopius* sp.) by spraying with cold water under a pressure of 60 lbs.

The action of cold-water spraying is, of course, mechanical rather than insecticidal.

Sterilisation of live stock is rarely practicable, apart from dipping operations. A method of fumigating mange-infected horses has already been described, and poultry can be treated in a very similar manner, a closed box, provided with a hole for the fowl's head to protrude through, being used, and an exposure to sulphur dioxide for ten minutes being arranged for.

Moore (1916) has experimented successfully with nitrobenzene as a fumigant for animals. Thus a sheep with very close wool was freed from 90 per cent of the Keds (*Melophagus ovinus*) upon it by exposure for twelve hours to the fumes of this substance in a closed box. Dog-fleas were found to leave the host at the end of half an hour and to be quite dead at the end of one hour, while the dog itself was unaffected.

A saturated atmosphere was used, the chemical being

allowed to evaporate from a cloth ; at 40 degrees F. one-tenth of a drop per cubic foot was sufficient to ensure that the atmosphere of the closed box would become saturated.

Enough has now been said to indicate the importance of restrictive measures in any comprehensive scheme of insect control. Too much stress cannot be laid upon the importance of preventing the spread of a pest from infested areas to uninfested ones, for the readiness and the rapidity with which such pests extend their sphere of operations is rarely sufficiently realised by agriculturists or horticulturists. Just one example may serve to make this point clear.

The Cotton Boll Weevil (*Anthonomus grandis*) first appeared as a threat to cotton in Texas, 1892. Within three years its depredations became so alarming that the U.S.A. Federal Board of Agriculture advised the State Government of Texas to prohibit cotton-growing over a belt of country in the path of the weevil and so restrict its advance. The advice was ignored. To-day this insect has spread over almost all the cotton-growing area of U.S.A., and seems to be almost uncontrollable. It is probably the most serious danger that has threatened any agricultural industry. Every acre of cotton land in U.S.A. pays nearly three dollars annual tax to this insatiable pest, and the cotton industry has paid and will continue to pay a heavy and bitter price for the ignorance and supineness of Texas authority in 1892.

# CHAPTER XIV

## CROP STORAGE

One of the concomitants of civilisation is the dependence of the members of a social community upon adequate methods of storing and preserving foodstuffs or other necessary commodities; only by such methods can the supply and distribution of essential products be regulated, or a stock for use in national emergency be provided.

The gradual evolution of non-agricultural sections of the community, industrial, commercial, professional, and leisured sections, has conferred increasing importance upon the question of crop storage, using the term in its broadest sense, and the study of storage problems has shed a vivid light upon the economic importance of insect depredators. To quote one example alone, the problem of reducing insect injury to stored grain in U.S.A. is, according to Hinds (1914), second in economic importance only to that of controlling the Mexican Cotton Boll Weevil, which is almost the most serious menace to agriculture in the world.

Consideration of the question of commodity-storage immediately indicates certain essential conditions which act inimically against such insect pests. Such conditions can be grouped generally into:

1. Conditions ensuring freedom of crop and container from insect pests, prior to storage. The container may range in size from a biscuit-tin to a granary. The term *crop* may be taken as covering not merely cereals, cotton-seed, baled cotton, tobacco, timber, etc., but also manufactured products, such as clothing, furs, flour, biscuits, cheeses, etc.
2. Secondly, conditions ensuring freedom from reinfection during storage.

A reasonable degree of freedom from insect pests can be obtained, of course, by mechanical cleansing methods.

Insect pests in flour and cereal mills, for example, are commonly introduced in second-hand sacks or machinery, as well as in infected flour or grain, and preventive measures based on cleanliness and careful inspection of incoming material will do much to minimise the possibilities of infection.

The sterilisation of used sacks or boxes, the fumigation of rooms or whole buildings, the treatment of floors with petrol or paraffin, the use of compressed air or vacuum cleaners for machinery, cracks, and crevices, all such measures tend to reduce infestation.

All commodities that are to be stored, especially cereal crops, should receive some preliminary cleaning operation; even grain infested with insect pests may be considerably improved by purely mechanical cleaning methods. Thus wheat that has become badly infested by Acarids (*Tyroglyphus farinae*, for example) can be much improved and further damage prevented by subjecting it to some process such as a blast of hot air followed by a blast of cold air, the grain being thus dried, most of the mites killed, and their bodies removed. In the "Hess Drier and Cooler," for example, the grain is passed from a band conveyer into a garner, whence it falls into a chamber containing a series of horizontal racks arranged one above the other, zigzag fashion. After subjection to a hot-air blast, the wheat passes into a similar chamber and receives a blast of cold air; then it passes into a hopper beneath and is thence discharged on to a band conveyer. Cold air is drawn through the lower chamber by a powerful fan, is forced over a series of steam coils, and thence passes over the wheat in the upper chamber (Newstead and Duvall, 1918).

Flour infested by *Tyroglyphus farinae* can be freed to some extent by passage through sieves of bolting-silk, but unfortunately such sieves are generally ineffectual in preventing the passage of eggs and faecal pellets.

The only radical method, however, of ensuring the freedom from pests of the product to be stored is that of *sterilisation*, the subjection of the product to a lethal agent. Sterilisation, as pointed out in a previous chapter, is an operation differing in principle from fumigation, in that the penetration, by a lethal agent, of a closely packed mass of infected substance is the objective, and in the availability of lethal agents other than chemicals: heat or cold, for example, or ultra-violet rays, X-rays, electricity.

Whatever the agent employed, it will obviously have to be such as will not injure the commercial qualities of the commodity; will not, for example, impair the germination

power of seeds, bulbs, plants, the pliability or colour of textile fabrics, the flavour of tobacco or foodstuffs. The agent must possess good powers of penetration, must be preferably non-inflammable, and without harmful effect upon the operator.

Such desirable qualities are rarely found in a chemical agent, but certain substances are known from experience to fulfil many of the conditions laid down above; such chemicals, for example, as *carbon bisulphide, carbon tetrachloride, carbon dioxide, sulphur dioxide, hydrocyanic acid.*

**Carbon bisulphide** is a clear volatile liquid having, if pure, a somewhat sweetish odour reminiscent of chloroform. It boils at 46 degrees C., the vapour being heavy, penetrant, non-injurious to fabrics or foodstuffs, and comparatively non-toxic to the operator, but it is unfortunately inflammable and liable to explode. Its successful application requires a warm atmosphere, not less than 70 degrees F., and an exposure of the product to its influence for a period varying from thirty minutes to one or two days, according to the degree of air-exclusion in the chamber.

In a reasonably air-tight container, with a temperature not below 70 degrees F., 5 lbs. of carbon bisulphide per 1000 cubic feet of air, or if the container be filled with grain or seeds say 1 lb. of the chemical to each 25 bushels, is the usual dosage, but if the container is not air-tight, double or treble this dosage may be necessary. The substance is usually placed in shallow receptacles, each holding not more than a pound, at the top of the container, and the length of exposure, if the container be closely packed with grain, is thirty to forty hours.

In a large container, a room or granary, for example, it is preferable to force the liquid bisulphide through an atomiser or a spray pump. In fact Hinds (1915) prefers this method for treating sacked cotton seed against the Boll Weevil (*Anthonomus grandis*) in Alabama. The apparatus consists of a three-inch air-pump, connected by pressure tubing with one branch of an ordinary quarter-inch Y such as is used in spraying work; upon this branch is a cut-off. The other arm of the Y has a similar cut-off and bears at its outer end a quarter turn with a metal cup at the top, so marked as to indicate accurately the quantity of liquid required per sack. The Y is connected with a piece of quarter-inch galvanised gas pipe about a yard long closed at the distal end with a metal plug sharpened to a point, so as to penetrate easily into the mass of seed. The terminal half of the tube is perforated with holes at distances of a few inches apart, for the vapour to diffuse through.

The perforated rod is driven into the sack of seed, the

cut-off on the cup-branch of the Y closed, and the cup charged with the requisite dose of carbon bisulphide. The cut-off is then opened, the liquid allowed to run down the pipe, the cut-off immediately closed and the one on the pump-branch of the Y opened. Two or three strokes of the air-pump are sufficient to drive liquid and vapour into the sack, and the rod is then withdrawn. With this method it is claimed that four men can treat 600 three-bushel sacks per day, two men manipulating the apparatus, the other two marking and removing the treated sacks. The dosage is 1 oz. of chemical to a three-bushel sack of seed.

Small quantities of seed or grain, however, can be treated quite easily and simply by using a barrel, or an iron dustbin, as a container and pouring the liquid directly on to the seed, 1 oz. of carbon bisulphide to 100 lbs. of seed, and allowing an exposure of thirty-six hours.

In Egypt, where that notorious cotton-moth, the Pink Boll Worm (*Gelechia gossypiella*), was introduced about 1910, much experimental work has had to be carried out to devise adequate methods of sterilising cotton-seed, since the pest spends a portion of its larval life-history within the seed, and is thus readily conveyed from place to place. Of the various chemical substances that have been experimented with, carbon bisulphide seems to be the most promising (Gough, L. H., and Storey, G., 1914), and the best method of applying it appears to be that of circulating the vapour from an evaporating chamber. A large-scale plant on this principle would require a battery of five or six container-vats. The gas would be pumped in from below, and a diffuser would be required above to draw off the gases. The circulating system would comprise an exhaust main and a blast main connected by a rotary or turbine air-pump. From these mains, branches would be given off to each of the vats; each branch would have a cut-off, so that any of the vats could be isolated from the general circulation. In practice, one vat would be filling with seed, the following filling with gas, the next two standing for an hour to allow the gas to act, the fifth would be discharging gas, and the sixth discharging seed. A large-scale apparatus on these lines, made by Thomas Cook & Son, at their Bulaq workshops, has been described by Storey (1915).

The great inflammability of carbon bisulphide has always militated against its use, particularly in hot climates, and various substitutes have been suggested, in particular *carbon tetrachloride*. This chemical, though certainly non-inflammable, is somewhat less toxic than the bisulphide and costs fully three to four times as much, so that it cannot be recommended,

if only on economic grounds, as a substitute for carbon bisulphide in mills and granaries, but would be useful on a small scale in quite air-tight containers and where inflammable materials are undesirable. It has been strongly recommended for the sterilisation of louse-infested clothing in gaols, small hospitals, asylums, etc. (Foster, 1918).

**Hydrocyanic acid gas**, though extensively used as a fumigant, is not so practicable a sterilisation agent owing to a certain lack of penetrative power. This difficulty can be overcome to some extent if a partial vacuum be created within the container. A small-scale plant devised to apply this principle to the sterilisation of seed was described by Sasscer and Hawkins (1915), and their method has been adopted on a much larger scale by the Federal Horticulture Board of U.S.A. for the sterilisation of baled cotton coming from localities (India and Egypt) where the Pink Boll Worm (*Gelechia gossypiella*) is present. At Boston, for example, the bales are conveyed to the sterilisation plant and placed upon moving platforms. The plant consists of two long cylindrical tanks about 100 feet long by 9 feet diameter, and two square tubes of 50 feet by 7 feet diameter. All these tanks can be tightly closed by doors at each end fitted with clamps.

The moving platforms can be run in and out of the tanks, so that the bales do not require handling. In a separate compartment are the engines which drive the vacuum pumps, and in a room above is a gas generator, a series of small tanks for the sodium cyanide and sulphuric acid. The dosage is 6 oz. sodium cyanide per 100 cubic feet of tank space. The actual procedure is as follows: The sealed tanks containing the bales are exhausted until the air pressure within is about 5 inches, that is to say, the vacuum gauge attached to each tank registers 25 inches, a "25-inch vacuum" having been produced. Gas is now admitted, the operation taking eight to ten minutes. Air is now allowed to enter until the pressure in the chamber has increased, until the vacuum gauge registers 5 inches. The pressure is again reduced to a 25-inch vacuum, five-sixths of the gas being sucked out and escaping to the outside. Pressure in the chamber is now increased until equal to atmospheric pressure, the doors cracked open and air sucked through the tanks to remove all traces of gas. The whole operation takes two and three-quarter hours, and by means of time-recording machines which show the length of time the different operations have taken, the authorities are able to ascertain whether the whole process has been carried out satisfactorily. A great number of bales can be treated at a time, the capacity of each large cylinder being

160 bales, and the whole plant is calculated to have a theoretical capacity of 3000 bales per day.

The obvious adaptability of this method of sterilising with hydrocyanic acid gas under reduced pressure to the treatment of grain or cotton-seed raises the question as to the effect of this gas upon seed, from the point of view of subsequent use, as cattle food, flour, and so on; cotton-seed, for example, can absorb a considerable quantity of this gas owing to the solubility of hydrocyanic acid in the oily-seed-content. Hughes (1915) asserts that the amount of gas remaining inside the seed after sterilisation is too minute to be in any way toxic to animals, and that since this slight amount is expelled, or destroyed for the most part when the seeds are crushed for oil extraction, no trace could be detected in the resulting oil.

Hydrocyanic acid gas would seem to have no deleterious effects upon grain or flour. *Sulphur dioxide*, however, a substance extremely toxic to the Flour Moth (*Ephestia kuehniella*), undoubtedly spoils the flour for bread-making. Treatment of such infested flour with *ozone* has been suggested by Edkins and Tweedy (1919), the Flour Moth being destroyed by exposure to a mixture of ozone and air, 100 parts per 1,000,000 of air for seven to eight hours; the operation must be carried out in closed receptacles, since 5 parts of ozone per 1,000,000 of air is injurious to man. Other chemicals in addition to hydrocyanic acid and carbon bisulphide have of course been suggested and tested as sterilising agents for stored products, such as, for example, *formaldehyde*, *phosgene*, *arsine*, *coal gas*, *carbon monoxide*, *cyanogen chloride*, *chlorpicrin*, *acetylene*, *sulphuretted hydrogen*, etc. Scarcely any other gas, however, except the two that have been discussed, has come into commercial use, and the majority of gases that have been tried have not been successful even in laboratory tests.

**Chlorpicrin**, however, a legacy from chemical warfare, seems to promise results of insecticidal value (Neifert and Garrison, 1920). Its toxicity to insects is nearly 300 times that of carbon bisulphide, but is less toxic to human beings. It is non-inflammable, easy to handle, and its vapour is twice as heavy as that of carbon bisulphide. It is, however, corrosive to metals, has an irritating lachrymal effect upon the operator, and its volatility is low.

According to Moore (1918), ½ lb. of chlorpicrin per 1000 cubic feet is toxic to *Bruchus obtectus* (Bean bruchid), *Sitotroga cerealella* (Angoumois Grain Moth), *Plodia interpunctella* (Indian Meal Moth), and *Ephestia kuehniella* (Mediterranean Flour Moth), all at temperatures below 60 degrees F., whereas to obtain similar results with carbon bisulphide some 3

to 8 lbs. at temperatures above 65 degrees F. are required. It is, however, more liable to impair the germination power of seeds unless they are dry and thoroughly aired afterwards.

**Para-dichlorbenzine** has been suggested by Duckett (1915) as a sterilising agent against pests of stored products and of garments, against cockroaches, ants, museum pests, etc.

It is a colourless, crystalline substance, volatilising readily, and has a colourless vapour with a peculiar ether-like odour; the vapour is non-toxic to mammals, but if at temperatures above 74 degrees F. has a paralysing and toxic effect upon insects. It is cheap and non-inflammable.

The dosage is from 7 to 10 lbs. per 1000 cubic feet of space for (below 85 degrees F.) thirty-six hours; above 85 degrees F. for twenty-four hours.

The use of **heat** as a sterilising agent is a method of long standing and is particularly effective against most insects. Insects are very susceptible to high temperatures, the ultra-maximum temperature—the temperature which will kill an insect instantly—being for the great majority of insects about 140 degrees F. A moderately high temperature, however, if applied for several hours is usually as fatal as a much higher temperature applied for a shorter time.

The following pests of stored products are destroyed instantly at the temperature recorded, unless otherwise stated: Acarids, 150 degrees F. for one hour; Pea and Bean Weevils (*Bruchus*), 146 degrees F. for fifteen minutes; Weevils, in general, 122 degrees F.; Larder Beetles (*Dermestes*), 140 degrees F. for an hour; Furniture Beetles (*Anobium*), 130 degrees F.; insects infesting flour-mills, 118 to 125 degrees F. for several hours.

Such high temperatures do not as a rule affect the quality of most stored products, rice and tobacco being the chief exceptions, nor do they impair the germination powers of seeds, but it is never advisable to go beyond the temperature known to be fatal to the insect pest that is being controlled.

The use of heat as a sterilising agent for stored products is at present, as regards large-scale work, confined to:

1. The treatment of cotton-seed in Egypt against the hibernating larvae of the Pink Boll Worm (*Gelechia gossypiella*).
2. The treatment of flour-mills in U.S.A. and Canada against the various pests of flour and grain, notably the Mediterranean Flour Moth (*Ephestia kuehniella*).

In Egypt, since 1912, when the presence of the Pink Boll Worm began to be a serious factor in cotton cultivation, much

experimental work has been carried out with methods of seed-sterilisation devised to kill the larvae hibernating within the seed. Sterilisation with such gases as carbon bisulphide and hydrocyanic acid gas and with high temperatures have given fairly successful results, but taking everything into consideration the employment of the latter agent is the most favoured.

The various types of machinery—*hot air machines*—invented for the high-temperature treatment of cotton-seed are numerous, and they have been described and criticised in various papers by Gough and Storey.

The difficulty in high-temperature treatment is to decide upon the range of temperature non-injurious to the seed but fatal to the contained larvae. It would seem that to kill the larvae instantaneously a minimum temperature of 140 degrees F. is necessary, but five minutes' exposure to a minimum of 124 degrees F. is just as fatal. As regards the seeds, wet seed can be raised to 140 degrees F. and dry seed to 150 degrees F. without impairing germination. The various machines that have been tested experimentally may be classed as:

1. Machines in which the seed is heated in a current of hot air; for example, the Ministry of Agriculture Hot Air Machine consists in principle of a box of iron insulated to prevent loss of heat and containing four endless bands of iron chains bearing trays to hold the seed. The seed is carried across the chamber on the upper surface of the upper part of the band; then upon the next band, and so on, being carried backwards and forwards across the chamber until discharged into the sacking exit. The box is filled with hot air wafted into it by a fan from a special generating chamber, a brick chamber surrounding the furnace.

   Other hot-air machines based upon this principle are the Hess Drier and Cooler, an American machine invented for conditioning maize, and the Neumann Machine.
2. Machines in which the seed is heated by radiation from steam pipes, *e.g.* Domains' Machine in which the seed is carried by an endless belt through a double-walled wooden box heated by steam pipes; somewhat similar in principle is Matsouchis' (Planta's) machine.
3. Machines in which the seed is heated by direct contact with metallic heating surfaces; *e.g.* Simon's Machine, designed really for drying malt but very successful for cotton-seed treatment. Other examples are Lenzi's, Macri's, Baker's, Murdock's, etc.

The use of high temperatures for sterilising cereal mills was first suggested and successfully attempted by Dean of the Kansas Experimental Station, 1910–1913. The use of hydrocyanic acid gas, whilst efficacious against most insect pests, had never been known to give complete satisfaction against the Flour Beetle (*Tribolium* spp.), the "cadelle" (*Tenebrioides*), and the Saw-toothed Grain Beetle (*Silvanus surinamensis*). On the other hand, all stages of cereal insect pests are killed by one or two hours' exposure to a temperature of 122 degrees to 131 degrees F. Only one treatment per annum is necessary, no preliminary cleaning is required, and the method is non-injurious to operator and to property.

The technique of mill sterilisation has been described by Back (1920). To obtain the high temperatures required, 118 degrees to 125 degrees F. being usually sufficient, it is necessary to heat the mill to a still higher temperature in order to allow for inequalities in the distribution of the heat. This temperature is obtained by steam pipe radiation, the installation of the steam piping being a heavy initial expense, which is, however, offset in course of time by the cheapness of the method in general. One square foot of radiating surface is usually sufficient to heat 50 to 100 cubic feet of space, the steam pressure being 25 to 50 lbs. The operation is preferably undertaken in summer.

The use of **Röntgen rays** for the sterilisation of stored products has been advocated, so far, only for the destruction of the Cigar Beetle (*Lasioderma serricorne*). Experiments in this direction have been described by Runner (1916). Skerett (1916) has described an X-ray apparatus in use at a factory in Tampa, Mexico, which can treat 40,000 cigars an hour. The cigars are conveyed, after being boxed, on an endless belt travelling between two X-ray tubes at the rate of twenty-three feet in twenty minutes. The tubes are operating at 45,000 volts and a current of 100 milliamperes is passed between them. The cigars are exposed to direct rays for four and a half minutes and to reflected rays for fifteen minutes. The machine is said to be quite successful and enables work to be carried on throughout the year without hindrance from *Lasioderma* infestation.

Effective storage conditions, designed to prevent re-infestation, are no less important than the cleaning and sterilising operations discussed above.

**Cold storage**, at very low temperatures, is perhaps the best-known method of storing food-stuffs under artificial conditions, although it must be admitted that cold-storage methods are aimed generally, not against insect pests, but against saprophytic bacteria, or against autolytic enzyme action. Still,

instances can be given of the application of low temperatures to the treatment of food commodities, with the definite aim of eliminating or excluding particular insect pests.

In the flour mills in the Prairie Provinces of North America, for example, temperatures of 25 degrees or more below zero are found to act fatally upon that troublesome pest the Flour Beetle (*Tribolium* spp.), although whether all stages are destroyed seems doubtful (Strickland, 1919).

Similarly, injury by Clothes Moths to furs, woollens, etc., can be minimised by storage at 40 degrees F. (Tweedy, 1912). The usual temperature of fur-storage rooms being 20 to 26 degrees F., risk of damage by these moths is not only entirely prevented, but the furs retain their fresh and glossy appearance, and since there is lessened evaporation of the sebaceous secretion of the pelts, their flexibility is retained.

Low temperature treatment is often useful in the case of products whose quality would be affected by heat. Thus rice infested with the weevil *Calandra oryzae* is sterilised preferably by exposure to a low temperature than to a high one, for although the weevils are killed in three hours by a temperature of 130 degrees F. or by exposure to a tropical sun, such heat treatment cracks the enamel of the seed and spoils the rice for milling (Lyne, 1918; Thompson, 1915).

Tobacco similarly can be freed from *Lasioderma* infestation by exposure to heat, to a temperature of 140 to 194 degrees F. in a steam chamber for half an hour, but tobacco so treated has a tendency to darken in colour and to become brittle. According to Pook (1910), a commercial process in Brazil is to expose tobacco for twenty-two days in perfectly dry receptacles to a temperature of minus 3 to 4 degrees C., or better still, to minus 10 degrees; all stages of the beetle being destroyed at these temperatures.

Back and Pemberton (1916) have described the fatal effect of low temperatures upon stages of the Mediterranean Fruit Fly (*Ceratitis capitata*) in citrus fruits. No eggs nor larvae survive refrigeration at 40 to 45 degrees F. for seven weeks, at 33 to 40 degrees F. for three weeks, or at 32 to 33 degrees F. for two weeks. Similar conclusions had been arrived at earlier by Lounsbury in South Africa and Hooper in West Australia, and it would seem that the storage temperatures for the preservation of fruit in transit from Africa to Northern Europe, America, China, Hawaii, are quite low enough to ensure that any fruit fly stages in the fruit are killed.

It is very often the case, however, that a temperature low enough to inhibit bacterial action and consequent decomposition of the stored commodity is not necessarily inimical to

insects, insects' eggs particularly being very resistant to low temperatures; further, the minimum temperature fatal to an insect is not easy to establish since the individuality factor is difficult to eliminate from the experiment, and, as already indicated in the discussion of climatic restraints, temperature is only one of the complex of factors that react upon the insects.

It follows, therefore, that low temperature storage, whilst keeping the commodity sound and lessening the attraction of insect pests to it, will not necessarily stop damage in a crop already infested, and the importance of freedom from infestation before storage cannot be too strongly emphasised.

**Exclusion of air**, or air-tight storage, as a method of retaining in the stored products the degree of cleanliness acquired by a preliminary cleaning or sterilising process, is of course limited in its application. Apart from canned goods this method has been used chiefly in connection with grain-storage. Before the Great War the question of wheat storage was of little interest in Great Britain, as wheat was not stored in large quantities for any length of time. During the war, when such storage was unavoidable, considerable damage was caused by Tyroglyphid mites, by Grain Weevils (*Calandra*), by Grain Beetles (*Tribolium, Silvanus, Gnathocerus*), by the Mediterranean Flour Moth (*Ephestia kuehniella*), and by rats and mice. In Australia, where enormous quantities of sacked wheat had to remain for several years awaiting shipment, heavy losses were incurred. In Great Britain, a special *Grain Pests (War) Committee* of the Royal Society was formed to investigate the problem. The question of Acarid infestation was dealt with by Newstead and others, the question of Insect infestation by Dendy and others.

A standard system of sterilising and screening imported wheat was devised, somewhat on the principle of alternate hot and cold blasts of air (Rathbone, 1919). One thousand bushels per hour could be dealt with, and in eight hours some 200 to 300 lbs. of dead weevils (442,000 to the lb.) could be secured from the 2500 bags of wheat treated.

Air-tight storage of wheat was recommended (Dendy and Elkington, 1918). It would seem that if weevil-infested grain be stored in hermetically sealed containers the carbon dioxide gas produced both by grain and insects acts as a narcotic aided by the diminished oxygen pressure brought about by the grain absorbing oxygen, and has a toxic effect upon the weevils, but no detrimental effect upon the cereal, unless kept longer than two years, when the power of germination becomes impaired. Other advantages derivable from the hermetic

sealing of grain containers are the absence of the condition termed "heating" and the absence of fungi, even when excessive moisture be present.

The evolution of carbon dioxide by the enclosed grain varies directly with the temperature and with the percentage of moisture present. There is a critical point of moisture percentage—somewhere between 13 per cent and 17 per cent—beyond which the production of carbon dioxide by wheat suddenly increases very greatly, so that the wheat stored in an air-tight receptacle very soon becomes non-inhabitable by grain pests, but below this point it takes a comparatively long time.

This dependence of carbon dioxide evolution upon a fairly high moisture content is somewhat unfortunate, since air-tight storage, though fatal to Acarids, is not fatal to their eggs unless the moisture content is below 11 per cent (Newstead and Duvall, 1918).

Prevention from Acarid infestation is best secured by keeping the moisture content of grain and flour below 11 per cent. Reduction of the moisture content to less than 7 per cent will also ensure freedom from *Calandra* infestation, according to the report of the special committee appointed by the Australian Commonwealth Advisory Council of Science and Industry to investigate the protection of stored wheat from weevils. Their recommendations are the careful avoidance of old weevil-infested bags and buildings and the dry storage of sun-dried wheat, which contains usually only 4 to 7 per cent of moisture. That is to say, in a fairly dry climate it should be possible to store wheat indefinitely without damage from weevils, if it is completely protected from the weather.

In a temperate country, such as Great Britain, the percentage of moisture in flour is usually between 12·5 and 14 per cent, so that flour intended for long storage ought to undergo some drying process; for example, such a method as that of the Hess Drier and Cooler.

Froggatt (1921) has suggested storage of shelled maize with carbon dioxide introduced from a cylinder, as a protection against weevils. A 500 gallon tank holding 60 bushels, for example, would receive 1 lb. of liquefied gas to each 12 bushels, the gas being easily measured by having the cylinder upon a weighing machine. Maize can be stored for a year in this way without injury, but one obvious drawback to the method is that grain cannot be withdrawn without the loss of some of the gas.

Instead of using such gases, Grove (1914) has suggested storage of grain or seed with naphthalene, 1 lb. to 2000 lb. of

maize. The chemical is placed in muslin bags and suspended in different levels in the bin. It should never be mixed with the grain, and such grain would require airing for six to twelve hours before use.

Enough has now been said to emphasise the importance of definite storage methods for commodities. Cleanliness and sterilisation before and during storage are the only general principles that can be indicated; particular methods of cleaning or sterilising still depend very largely upon the nature of the commodity, the nature of the infestation, and the climate, or the economic conditions.

# CHAPTER XV

## BAITS AND TRAPS

THE employment of trapping devices against insect pests is not so simple nor so easy a measure of control as its antiquity or its widespread occurrence would suggest, nor can it be said that the results thus obtained always merit the amount of ingenuity that has been expended in obtaining them. Not only does the success of such measures depend almost entirely upon accurate knowledge of insect habits and behaviour in general, but it requires a careful adaptation of the standard trapping device made use of to the particular idiosyncrasies of the insect species whose elimination is desired. Neglect of this latter point may lead to disappointing results, very often when the particular method employed is one of proved merit against other insect species or under other environmental conditions, but when based upon careful consideration of the life-cycle and habits of the insect aimed at, trapping devices are undoubtedly among the most valuable of insect control methods.

Such devices are of infinite variety, but they can be grouped roughly into four main types, namely, **bait-traps, shelter-traps, mechanical traps,** and **light traps.**

The simplest form of bait-trap is perhaps that which utilises the kind of foodstuff to which the insect is particularly addicted. A commonly recommended measure against wire-worms (larvae of Elaterid beetles), for example, is the use of pieces of potato, or turnip, buried a few inches below the surface of the ground; these are periodically examined and the attracted larvae destroyed. Such baits are preferably laid down in lines, five feet between successive baits and six to ten feet between adjoining lines, and the baits should be examined and renewed five times during the growing season. It must be pointed out, however, from accurate field observation, that not all species of Elaterid larvae are attracted by potato, so that the use of any one type of bait against all cases of wireworm infestation is not to be recommended. The constant examina-

tion and renewal of baits renders the method somewhat laborious considering the results usually gained, although it is claimed that as many as 4000 larvae per acre can be secured by such traps (French, 1913).

Against sucking insects, traps baited with sweetened substances are often of value. Allusion has already been made in Chapter X. to the attraction exerted by fermentation products, notably certain alcohols, upon Muscid flies. In France, such substances are extensively used in traps in order to attract adults of the Vine Moths (*Clysia* sp. and *Polychrosis* sp.). Lafforgue (1914) asserts that if success is to attend such traps it is essential that the sweetened bait should be undergoing alcoholic fermentation. A 10 per cent aqueous solution of molasses with the addition of about one-twentieth of its volume of wine-lees has been found very satisfactory. The wine-lees need only be used in starting the trap, since as more molasses solution is added to keep up the level of fluid in the trap, it is fermented by the older portion of the solution. The number of traps to a vineyard should average 80 per acre, each trap requiring about 6 oz. of molasses.

The chief points to be observed are the avoidance of strongly smelling plants, such as *Ampelopsis*, Ivy, Currant, in the vicinity of the traps, and the avoidance of direct sunlight; warm still weather is the best time for setting the traps; cool windy weather prevents the moths from flying far and disturbs the scent of the baits. Good results are obtained particularly from traps placed in the paths at the ends of the rows of stocks. The addition of an unmated female to the trap generally produces an exceptionally large catch, but one consisting chiefly of males (Feytaud, 1916; Dewitz, 1913).

There is one very great objection to the ordinary bait-trap, whether intended for biting or for sucking insects, and this is the rapidity with which the bait becomes devoured when the insects are very numerous, and the consequent labour and expense of frequent renewal. Against such insects, therefore, as surface-caterpillars (cutworms), locusts, ants, cockroaches, fruit flies, the addition of some poisonous substance to the bait is desirable where possible.

The standard type of poison-bait against locusts, grasshoppers, and cutworms is a mixture of *bran*, *Paris Green*, *molasses*, and *lemons*, of which the proportions of the constituent substances vary in different recipes. The so-called "Kansas Bait," for example, consists of: bran, 50 lbs.; Paris Green, 2 lbs.; molasses, 4 quarts; oranges or lemons, 6 fruits; water, 5 to 6 gallons. 5 lbs. per acre is the usual dosage.

The bran and Paris Green are mixed in the dry condition;

the fruit juice is squeezed into the water and the minced pulp and peel added. The molasses is next added to the water and the whole mixture poured over the mixed bran and arsenic. The mixture is finally stirred thoroughly until the bran is moistened and has a crumbly consistency (Criddle, 1920).

There are a number of variations from this formula in practical use. Thus the use of brown and white sawdust, maize, dried beet slices, crushed olive stones, rice bran, cotton-seed meal, finely ground peas, or even paper, has been suggested and tried instead of bran. Generally speaking, such substances are less efficient than bran, but will serve when bran is unobtainable. Finely powdered white arsenic may be used instead of Paris Green and is cheaper. Some authorities consider the addition of molasses to be unnecessary. Artificial lemon extract or amyl acetate may be used instead of chopped lemons, and in some cases had been found to be more effective.

Other poison baits besides the bran mash type have been used with success against locusts, and mention may be made of the "Criddle Mixture" consisting of : fresh horse manure, 15 gallons by measure ; Paris Green, 1 lb. ; salt, 1 lb. Sufficient water is added to make a moderately wet mash, and the ingredients are then thoroughly mixed (Criddle, 1920).

A device for the even distribution of such locust baits has been described by Parks (1917) from experience in Western Kansas. It consists of a waterproof canvas bag slung from the shoulders of the operator, and provided with a canvas sleeve 12 inches long, 13 inches in circumference at the upper end, 8 inches at the lower end ; the lower end of the sleeve fits tightly over a swinging tube of galvanised iron which is 28 inches long, $2\frac{1}{2}$ inches in diameter at the upper end, and $1\frac{5}{8}$ inches at the lower end. Over the opening at the lower end two short wires, each somewhat U-shaped, cross each other at right angles at the centre and about one inch below the opening of the tube, and are soldered together where they cross and to the edge of the tube. The mixture can thus be scattered thinly and evenly.

Poison baits should be put out in the afternoon against locusts, or at sundown against cutworms, so that the baits are not dry before the insect gets at them. They should not, of course, be placed where other animals may find them. As a rule such baits affect locusts somewhat slowly, eight hours to several days sometimes elapsing before the insect succumbs, and many farmers are opposed to their use as they consider that between the time of poisoning and death the insects have time to destroy the crop. Experiments have shown, however, that although the action of the poison is rarely instantaneous,

the poisoned individuals either cease to feed or consume very little, certainly less than one-ninth as much as unpoisoned ones.

In the case of many insects, an attractive bait is not absolutely necessary. Any powdered substance applied to a cockroach, for example, is eventually taken into the mouth owing to the habit the insect has of cleaning its legs and antennae by drawing them through its mouth-parts. Thus any poison, even if non-attractive, will tend to reach the insect's alimentary canal, if scattered about in places where it is likely to get on the legs, and the addition of an attractant to the substance is not required.

Of a wide range of substances tested in this way upon cockroaches, the most effective would appear to be *sodium fluoride* mixed with an equal weight of some diluent such as flour. *Borax*, although frequently recommended as a cockroach poison, acts too slowly to be of practicable use. *Phosphorus pastes* are somewhat variable in their action (Scott, Abbott, Dudley, 1918). *Arsenical* preparations are not very successful, cockroaches showing remarkable tolerance to such substances.

*Poisoned syrups* are very successful against many insects. In California such syrups are extensively made use of in orchards infested with the Argentine Ant (*Iridomyrmex humilis*). The syrup is placed in small containers of tin or paraffined paper, which are hung, one to each tree, throughout the orchard, the ants entering through small holes in the sides.

The most effective syrup is a modification of the original Barber formula, and comprises: water, 11 pints; tartaric acid, crystallised, 7 grams; benzoate of soda, 9 grams; granulated sugar, 12 lbs.; honey, strained, 2 lbs.; sodium arsenite, chemically pure, $\frac{3}{4}$ ounce—a total of $2\frac{1}{2}$ gallons of syrup.

Ten pints of water are warmed over a slow fire in a thoroughly clean vessel. When tepid add the tartaric acid, then the benzoate, and then the sugar, slowly, while stirring to prevent burning. Measure the depth of the liquid with a stick. Slowly bring to the boil and allow to simmer for about thirty-five minutes. Remove from the fire and add water to allow for evaporation. Stir in the honey before the mixture cools. Then add the sodium arsenite which has been dissolved in one pint of hot water and partially cooled. Stir thoroughly (Woglum and Borden, 1921).

Similar syrups are very successful against house-flies and fruit flies. A method used in South Africa against such flies is the spraying of syrup composed of one pound of sodium arsenite and two gallons of treacle, in ten gallons of water,

upon any article having a smooth non-absorptive surface, such as suspended bottles, tins, tree branches, etc. (Mally, 1915).

Arsenical substances are not, however, desirable for use in households or in proximity to food-stuffs. Of the wide range of substitutes for arsenical poisons that have at various times been recommended for the destruction of house-flies, only two, namely *formaldehyde* solution and *sodium salicylate*, can be said to be really effective.

Phelps (1916), as the result of extensive tests, recommends that formaldehyde should be used as a 1 per cent solution, that is to say a $2\frac{1}{2}$ per cent solution of the commercial "formalin." It is less effective than arsenical preparation, but its loss of efficiency with decreasing temperature is less.

A 1 per cent solution of *sodium salicylate*, although slightly less efficient than formaldehyde, has certain advantages over it, particularly for household use. It is less objectionable substance when in concentrated form, and not being volatile does not lose in strength.

For household use, either of these solutions are prepared by the addition of three teaspoonfuls of either the 40 per cent solution of formaldehyde (formalin), or the powdered sodium salicylate to a pint of water, or to a pint of equal parts water and milk.

Methods of distributing such fly poisons vary, but the placing of such fluids in shallow dishes throughout the house is not to be recommended. A preferable method is nearly to fill a glass tumbler with the solution, to place a circular piece of blotting-paper somewhat larger in diameter over it, and over this again an inverted saucer. The whole device is turned upside down and a match is inserted under the edge of the tumbler to allow access of air. The blotting-paper will remain in a moistened condition until the entire contents of the tumbler have been used, and the strength of the solution will remain uniform.

The efficacy of formalin as a fly-poison depends to some extent upon the freedom of the exposed fluid from formic acid and, to a less extent, from methylamine. It should be colourless, free from a fishy smell, and limewater should be added to neutralise any acid present. Lloyd (1920) recommends the following formula: 5 to 6 per cent formalin, 50 per cent limewater, 2·5 per cent sugar and water to make 100.

A transition between *bait-traps* and the next class of traps, namely *shelter-traps*, is afforded by what are termed "trap-crops." A trap-crop is a crop which is sown earlier than the more valuable main crop so that it comes up before it, and attracts large numbers of insect pests which would otherwise

oviposit upon or attack the main crop. The trap-crop is then ploughed under or destroyed. The trap-crop, of course, must be some plant which is readily attacked by the main crop pest and which will mature much earlier than the main crop.

In those areas of the U.S.A., for example, where the Chinch-bug (*Blissus leucopterus*) does great damage to wheat, the suggestion has been made that some crop such as millet should be planted around a sown wheatfield to isolate it from neighbouring infested cornfields. When the invading chinch-bugs have reached the trap-crop it is sprayed with paraffin and ploughed under. In other cases it may be found advantageous to sow a small strip of the field rather earlier than usual, and as this portion will be above the ground before the remainder of the crop, it will act as a trap-crop since the particular pest will concentrate upon it. The trap-crop may then be sprayed or burned with a flame thrower and the future brood thus checked.

Trap-crops may also be used as poison baits. Parsons (1916) has suggested that the outer edges of a crop area and a central plot should be sprayed with Paris Green or lead arsenate (3-5 lbs. Paris Green, 4 lbs. soap, 100 gallons water). These trap areas are cut later than the crop, since the insects will migrate to the trap-crop when the rest of the field is harvested. The trap-crop can then be burned.

A similar use of *trap-trees* and *trap-logs*, though a somewhat laborious and expensive procedure, is very often justified by results when a very severe outbreak of a tree-boring insect is in question.

In Polynesia, one of the greatest obstacles to the cultivation of sugar-cane is the presence of the Hawaiian Sugarcane Borer (*Rhabdocnemis obscurus.* Boisd.), the grub of a beetle belonging to the weevil family Calandridae, which, hatching from an egg laid beneath the epidermis of the cane stalk, bores into the stalk and completely honeycombs it with tunnels running parallel to the long axis. In the Fiji Islands, a method of trapping the beetles is used which consists of splitting cane stalks and placing pieces around the edges of the fields and within the rows at certain intervals. The method is thus described by Koebele (1900) :

" At the request of the Colonial Sugar Company, we looked into the matter with a view of getting rid of the beetles the best way possible ; all sorts of devices were employed, and none worked better than pieces of split cane about 12 inches long, placed along the edges of the fields and through the same at intervals of 12 to 18 feet ; thus with seven little Indian girls,

I collected over 16,000 beetles in some four hours, and the same little girls brought in, the following noon, over 26,000 beetles.

"The method was kept up, and followed on all the plantations for the next three years, or until no more of the borers could be found. Tons of beetles were brought in at the Nausori mill alone, and the expenses of collecting were practically nothing compared to the cost at Lihue, where such work had to be done by the day-labourers. About four cents per pint of the insects was paid to the children. The result has been highly satisfactory, for ever since the last five years, the cane borer has not been a pest in these islands."

The use of trap-trees and trap-logs is more usually prevalent, however, against beetles attacking forest trees, particularly such beetles as hibernate or breed in decaying or felled trees. Thus the Pine Shoot Beetle (*Hylurgus piniperda*), a Scolytid beetle very injurious to the young shoots of Scots Pine, selects about early April or late March a sickly standing tree or the stem of healthy trees which have been felled during the previous winter, in order to excavate the characteristic branching galleries between bark and wood in which the eggs are laid and the larval stages passed through.

The second generation of beetles appears about the end of June, and tunnels similarly in trees which have been felled in late spring or early summer. The second brood emerges in autumn and immediately bores into the pith of young leading shoots of the pine and causes great damage.

The generally recommended method of control, therefore, is to select certain trees, fell them in September and bark the logs in May or June to secure the first brood, and to fell in June and bark in September for the second brood.

Speaking generally, the preparation of trap-trees is as follows. For standing trap-trees, two rings are cut round the trunk, about a hand-breadth apart. The bark between the rings may be removed (girdling) or may be left (double ringing). The crown of the tree may be sawn off, or the branches may be lopped off. Standing trees make very attractive traps but are troublesome to prepare, and the attack and development of the attracted beetles are difficult to observe. It is therefore more usual to fell the tree. Their attractiveness is often increased by scarifying the upper surface longitudinally, the resulting resinous odour attracting such species as *Hylastes*, *Pissodes*, and *Hylobius*. The position of the tree, the season of the year when it is felled, and the nature of its surroundings, must all be taken into consideration; trees felled in spring or early summer are rarely ready in the same year and by

the next season are generally useless. Winter is the best for felling as a rule (Sedlaczek, 1921).

The *shelter-trap* is based upon the habit possessed by many insects of wintering beneath loose cover, loose bark, boards, crevices in walls, etc. The shelter-trap in principle is an artificial hibernation-quarters which can be examined and the contained insects destroyed.

Larvae of the Codling Moth (*Cydia pomonella*), to take a typical example of an insect amenable to this method of control, emerge in midsummer from infested apples; if the fruit be still on the tree they crawl down to the trunk; if the fruit has fallen the majority of larvae crawl up the trunk of a tree from the ground. Their desire, of course, is to find a shelter beneath loose bark under which to pupate either in autumn or in the following spring. If, therefore, the trunk of the trees be well scraped so as to remove all loose bark, and a piece of sacking or a band of straw be tied around it, large numbers of larvae will be attracted and will spin their cocoons beneath it.

The materials used for such bands vary. Temporary materials such as hay, paper, or other cheap material are afterwards burned with their contained larvae. Permanent bands of cloth can be used over and over again. The most efficient materials would seem to be some dark heavy material; muslin is quite inefficient. In practice, fruit-growers use almost any material, such as old clothes, burlap, and canvas. The band should be long enough to go round the tree more than once and should be 12 to 18 inches in width, so that it can be folded longitudinally, into two or three thicknesses, to a width of 6 inches. After wrapping the band round the tree, a small nail should be driven through the ends and the head of the nail so nipped off as to leave a sharp point. Subsequent removal of the band is readily effected by pulling the ends off the nail, and replacement by pushing them down again over it.

Generally, one band per tree is sufficient, but where trees are large and have a number of large branches it is advisable to band such branches as well as the trunk. The bands should be examined every ten days from about the middle of June to the end of August, and the contained pupae destroyed; or the bands, if of a temporary nature, are better placed in boxes provided with covers of gauze of not more than 2 mm. mesh. Such boxes are kept under cover during winter, but about the middle of March should be placed in the orchards. The parasites of the contained larvae can thus be liberated, whilst the adult moths are retained.

The objection frequently raised against such trap-bands, that they require attention so often, perhaps eight to ten times in the season, may be overcome to some extent according to Siegler (1916) by using a twelve-mesh wire screen cloth, six inches wide and long enough to encircle the tree. The trunk is first banded with a two-inch wide strip of burlap, and the wire screen is tacked over the band. No moths can escape through this size of mesh, but larvae can readily enter, and the trap requires attention only at the beginning of each year.

The habit of larval migration is found very commonly in other insects. Traps designed to catch house-fly larvae, for example, can be based upon the same principle.

Hutchison (1915) has described a maggot-trap which has been tried experimentally with marked success at the Maryland Agricultural College, U.S.A. It consisted of a concrete floor 22 feet by 12 feet, around which was a rim 4 inches high. This was flooded with water or weak disinfectant to a depth of half an inch. Standing upon this concrete basin, and raised one foot above it, was a wooden platform made of laths one inch wide and one inch apart. Manure was piled upon this platform to a maximum height of 4 feet and sprinkled with enough water each day to moisten it thoroughly. Now the larvae of house-flies (*Musca domestica*) when pupation draws near migrate from the moist regions of a manure heap and seek the comparatively dry regions. If the manure be wet throughout, they will leave it to pupate in the ground, in cracks or crevices, anywhere where conditions are dark and dry. In this case, the migrating larvae fall into the weak disinfectant and are drowned. Some 98 per cent mortality was estimated to occur.

A maggot-trap somewhat differently constructed has been described by Baber (1918) from large scale experience of its working in South Africa. The manure heaps are isolated by sinking around them a gutter of sheet metal, $3\frac{1}{2}$ inches deep, which is not the usual V-shape but has concave sides, being in section almost spherical; larvae cannot escape from such a gutter and they are driven from the manure to the gutter by the internal heat of the pile (130-160 degrees F.). The trap is rectangular, three gutters being flush with the ground, the fourth being movable and simply laid on the ground, and the earth from the manure heap to it being banked up so that the larvae can crawl into it without difficulty. The ends of this movable gutter are open so that the larvae can drop into the long sunk gutters on either side. This loose gutter is moved along as the heap increases, whilst the manure

at the other end may be removed after sufficient time has elapsed to ensure the destruction of the larvae there.

This type of maggot-trap leads on to the question of *mechanical traps*, since such traps, which are not usually based upon chemotropic, or phototropic principles, merely catch and imprison the insect mechanically and are divisible into (*a*) *trap-trenches*, and (*b*) *adhesive traps*. The type of trap just described belongs to the trap-trench category.

A trap-trench is just a ditch, about 2 feet wide and 18 inches deep, the side next to the threatened field being usually perpendicular. At intervals along the trench, deep holes are dug. In these holes the insects accumulate and can be subsequently killed by hot water, by oil, or by flame.

Such trenches can, of course, only be employed against those species or life-history stages of insects which are unable to fly but migrate on foot from one crop-area to another. Surface caterpillars and the wingless immature stages of locusts and grasshoppers are particularly amenable to this method of control.

Thus when fields infested with the cutworm *Euxoa segetum* are surrounded by trap-trenches whose sides have a slope of 45 degrees, the caterpillars in migrating to fresh food areas are caught in large numbers and are unable to get out of the trenches, being apparently unable to negotiate a slope of 30 degrees or over. If the earth is loose, a few larvae may escape by burrowing, but if the bottom of the trench be raked and the trench cleared daily they are recovered (Herold, 1920).

Such trenches can be very successfully employed in locust control work. In the case of the Moroccan locust (*Dociostaurus maroccus*), in Asia Minor, to quote a recent example, strips of zinc one foot high extending for half a mile across the line of invasion were erected, a trap-trench being sunk on the side towards the locusts.

Only thirty-five to forty men were necessary to secure 100 metric tons of locusts, whereas under the old system of driving the locusts together at least one thousand workers would have been required (Bredemann, 1918).

Possibly the trap-trench has found its greatest practical application in the control of the Chinch-bug (*Blissus leucopterus*) in the United States. During the early summer, the young chinch-bug obtains abundant nourishment from the sap-stream of wheat, barley, and other cereals, but as the wheat begins to ripen the bug must seek food elsewhere or perish; it must migrate to the nearest corn, cane, or millet field.

The time of migration depends upon the food supply and commences when the wheat ripens or is cut. If the food supply

holds out until the bugs are mature, they migrate both on foot and on the wing. Chinch-bugs migrating on the wing can neither be trapped nor destroyed. If the wheat, however, ripens or is cut before wings have developed, the crawling bugs can easily be caught. It is important, therefore, that an infested crop should be cut as early as possible, prior to trap-trenching.

Two types of trench can be used, according to weather conditions. If dry, hot weather prevails, the " Dusty Furrow " is made. A strip of land 6 to 8 feet wide should be ploughed next to the infested field, and the ground thoroughly pulverised to a dust with a disc-harrow. A weighted log 6 to 8 feet long with a pointed end, or a trough of heavy timber, is now drawn lengthwise backwards and forwards until a deep furrow in the dust is created. Some authorities recommend a double furrow, made by a pair of four-foot troughs held parallel and 12 inches apart by a couple of strong 2-by-4-inch pieces nailed firmly across the top.

In any case, the sides and bottom of the furrow must consist of a deep fine dust.

As the infested fields are harvested, the migrating bugs are caught in the furrow and may be destroyed by flaming the sides and bottom of the trench at regular intervals with a petrol-blast torch having a flame at least 6 or 8 inches long.

If the weather be wet, the " Tar or Oil Line " is employed. This is essentially a smooth surface about 1 foot wide between infested and uninfested fields, along which at 10 to 30 feet intervals holes about a foot deep are made. On the smooth surface, tar or asphalt road oil is poured from an old kettle or a watering-can with the rose removed, but passages are left from the field to the holes, so that the migrating insects, deterred by the oil, converge towards the holes and are trapped.

A variation of this method is to plough a double furrow along the line. The top of the ridge between is then made smooth and the line of oil is placed upon it, holes being provided as before (Headlee and M'Colloch, 1913; Hudson, 1914).

*Adhesive traps* vary greatly in details of construction, but agree in depending for success upon the use of a sticky substance to entangle the insect.

The adhesive substance used in the preparation of " fly-papers " for the trapping of house-flies is usually a mixture of resin and an oil, but the variety of recipes is enormous. Generally speaking, a parchment paper is used or a paper made oil-proof by being dipped in glue-water (1 oz. glue in 3 oz. water) and dried.

The adhesive mixture may be one of the following or a very similar preparation :

(*a*) Resin, 3 parts ; cotton-seed oil, 1 part.
(*b*) Resin, 10 ; sesame oil, 5.
(*c*) Venice turpentine, 1 ; American turpentine, 4 ; castor oil, 2.
(*d*) Pine resin, 25 ; boiled linseed oil, 18 ; yellow wax, 2 ; castor oil, 5.
(*e*) Colophony, 6 ; rape-seed oil, 4 ; resin, 3.
(*f*) Resin, 8 ; turpentine, 4 ; rape-seed oil, 4 ; honey, $\frac{1}{2}$.
(*g*) Resin, 16 ; molasses, 3 ; linseed oil, 3.
(*h*) In a tropical climate : resin, 12 ; ground nut oil, 5 ; crude vaseline, 1.

It is brought to the boiling point and immediately applied to the paper.

A very good example of the value of adhesive traps is afforded by the case of the Winter Moth (*Cheimatobia brumata*) and the March Moth (*Anisopteryx aescularia*) in Great Britain. The larvae of these Geometrid moths feed upon the foliage of apple, plum, and (in the case of *Anisopteryx*) upon pear during spring and early summer. The popular names are derived from the fact that the moths hibernate as adults through the winter and emerge between January and the end of March in order to oviposit. In both cases, the eggs are laid high up on the tree, around buds and small branches, in crevices of twigs and boughs, and as the female is wingless she has to crawl from the ground where she has hibernated, up the tree trunk. She can therefore be trapped before she can oviposit, by bands of paper covered with a sticky grease, placed round the tree and kept in position from September to March.

The value of this "grease-banding" procedure has been disputed by some authorities. The method is of course not infallible, there being a possibility of some females being carried up into the trees by the males, in copulation ; but there is no doubt that if carefully carried out, the method gives very good results ; as many as 300 females have been found upon a single band. The chief and most pertinent objection to the method is that it applies only to these two pests, and as the greater part of foliage damage in fruit trees is caused by Lepidoptera whose females can fly up to the branches, Tortricidae, for example, the banding-method does not do away with the necessity for insecticidal spraying later in the year and is therefore redundant.

The banding paper should consist of strong packing or parchment paper, should be grease-proof, so that the poisonous grease does not soak through and injure the tree. The band

should be about 5 inches wide; it is pasted to the tree with flour paste about 2 to 4 feet from the ground and then firmly tied with strong string or iron wire at both upper and lower edges, so that no insect can crawl beneath. The grease is then smeared evenly over the band either with the palm of the hand or with a stick having a broad end.

If the band is placed too near the ground, and this is especially the failing in the case of half-standard trees and bush apples, it will not be satisfactory since the first shower of rain will splash mud upon it. Another common cause of failure is the use of home-made adhesive, which, in hot weather, melts and runs down the trunk, and when subjected to frost and rain is apt to dry and harden. Such preparations are generally useless against the long-legged Winter Moth, and it will be found advisable to use a commercial product such as "Tree Tanglefoot." Many commercial products have the advantage of being applicable directly to the bark, but in practice it is preferable to use an intervening band of paper, the trunk being kept cleaner thereby and the removal of the band being readily effected.

Such bands should be in position by the end of September and should remain until the end of March, being examined periodically.

Various other adhesive traps are used against insect pests, their application and the form of the particular device employed depending largely upon the practical ingenuity of the operator.

"Flea-beetles," the small Chrysomelid beetles that ravage various truck crops, turnips, potatoes, tomatoes, radishes, and the like, afford a case in point, since their jumping habits can be taken advantage of in control operations.

In fighting the Turnip Flea-beetle (*Phyllotreta nemorum*) of Great Britain, for example, a light framework upon wheels and having tarred boards fastened to the underside can be drawn over the growing crops. The disturbed beetles leap upwards and are caught on the sticky surface.

In the case of the Hop Flea-beetle (*Psylliodes punctulata*) in British Columbia, sheets or boards covered with tar are placed under the hop-vines and the latter are jarred with a stick, so that the beetles are shaken off on to the sticky surface.

Similar methods are in use in most countries against weevils, sawfly-larvae, aphides, leafhoppers, and chafer beetles attacking bush fruits, vines, hops, etc.

*Light traps* of one kind or another have long been in practical use, and very many simple traps not usually classed as light traps depend upon the attractant or the repellent effect of light upon insects.

Take, for instance, that common form of house-fly trap known as the Hodge Fly-trap. It consists of a wire gauze balloon having a basal opening so arranged as to admit but not to liberate flies. It is fitted over an aperture in the lid of a dust-bin. Flies that hatch in the darkness of the bin make for the light, are admitted into the trap and retained. The trap is made in two separable halves, so as to be readily emptied.

An example of a trap based upon negative phototropism is afforded by the very simple mosquito trap described by Lefroy (1911) and based upon the habit possessed by many mosquitoes of seeking dark corners during the intense light of the tropical day. It is merely a box lined with dark cloth. It is placed, with the lid slightly raised and kept open by a catch, close to where mosquitoes collect during the day and as high up as practicable; it is placed into position preferably an hour after sunrise or at mid-day. The bookshelves, hangings, etc. of the room are then dusted and the disturbed insects take refuge in the dark box. The lid is finally snapped to, and a teaspoonful of petrol poured in through a hole. After five minutes the stupefied insects are shaken out through an opening and burned, and the trap re-set.

The attraction of artificial light for nocturnal Lepidoptera has been made a basic principle for many different forms of trap. Perraud in 1904, discussing the attraction of monochromatic light for moths, asserted that different colours of light exerted differing degrees of attraction, according to the following sequence: white light 33·3 per cent, yellow 21·3 per cent, green 13·8 per cent, orange 13 per cent, red 11·5 per cent, blue 3·9 per cent, and violet 2·2 per cent. Other investigators, however, have considered green light to be the most attractive, and Von Neustadt (1913), using incandescent lamps containing mercury vapour, which is rich in violet and ultra-violet rays, caught 54,500 moths in ten successive nights.

The constructional details of trapping-contrivances based upon the light-attraction principle vary enormously from simple arrangements of naked lights, or hurricane lamps set in a pan of water, to complicated and expensive box traps.

One design of trap is intended for carriage on a waggon or motor car and is provided with a suction apparatus intended to draw the insects attracted by the light, into a wire-gauze cage which can be removed and fumigated. This form of light trap has been suggested as a satisfactory device against locusts. The cost of construction of such a portable trap would seem to be, however, a fatal drawback to its general adoption.

Criddle (1918), discussing the value of light traps from an

economic standpoint, has pointed out the many disadvantages attending their use. Even with conditions most favourable to their employment, the number of insects caught, both as regards species and individuals, is comparatively small. The essential meteorological factors necessary to success are warmth and cloudiness, absence of moonlight or stormy atmosphere, and the presence preferably of light rain. Such weather conditions, of course, will rarely occur together. It has been asserted by Turner (1920), though from scanty data, that the night-flying habits of moths are not greatly influenced by humidity and temperature, but such factors as strong winds, heavy rain or fog, undoubtedly restrict flight. Another serious drawback is the numerical preponderance of males over females caught in the traps, and the number of hymenopterous parasites that fall victims.

So far as present experience goes, therefore, light-traps are not a practical method of insect control.

It may be added, in conclusion, that no form of trapping device can be considered as anything but a method supplementary to other control measures. Trapping devices are undoubtedly of great value when an overwhelming invasion of some pest occurs, but unless the infestation is likely to be severe, trapping will usually be found too laborious and costly for large scale application.

# PART IV

## LEGISLATIVE CONTROL

## CHAPTER XVI

### LEGISLATION

THE consideration of various methods of Insect Control outlined in the preceding chapters will have indicated that their effectiveness is dependent not merely on the correct choice of a method best suited to the immediate problem, but upon the simultaneous application of the method selected to the *whole* area of infestation. Such a standardisation of control operations, so to speak, can only be brought about by making their observance a legal obligation upon the agriculturists concerned, through the enactment of definite Restriction Orders. In almost every civilised country, therefore, legislation relating to insect control exists to a greater or lesser extent.

In view of the immense difficulties of insect suppression, the creation of such legal enactments, however, would seem to be a policy of doubtful value unless accompanied by a system of educational propaganda to enlighten the agriculturist as to the necessity for such measures. Unless he has been led to appreciate their importance, and unless his hearty co-operation is available, there will be always a tendency towards their evasion ; the disaffection of a single farmer may be fatal to the success of a scheme of control measures, and lack of appreciation of this point has been in the past a very great obstacle to the success of legislation measures. Since it is usually difficult to show immediate tangible results from restrictive orders, and since such measures often necessitate irksome and seemingly useless restrictions, it has frequently happened that much opposition has been raised to the passing of legislative enactments, especially on the part of prominent horticultural interests. It is only recently that the true value of such legislation has been realised, namely that it is the *co-ordinating agent* in any large scheme of insect-control

measures amongst agriculturists and is not in itself a method of control.

It must be clearly understood that the popular impression that the object of legislation against insect pests is necessarily to exterminate them is erroneous. To annihilate an insect pest is rarely possible. In the career of an insect pest, certain phases occur. In the first place, it may have the status merely of an insect and not that of an economic species and may enter, probably unobserved, a new territory. Immediately, the insect finds itself in a new environment, and consequently, even if its numbers do not suffer a severe check, progress is necessarily slow. Later, its numbers begin to increase unduly, owing possibly to a lack or infrequence of natural enemies, and in about ten years, or even less, it becomes noticeable in epidemic form. Should its habits be such as to annoy the community it will be classed as a minor pest, or even as a "Second Class Pest," that is to say, a pest severe in its infestation but confined to a limited area. At this stage, vigorous control measures will probably severely check the insect; but should the infested article be a commercial commodity with a wide distribution, the chances are that the insect will have spread extensively and become well established before detection, or before there is anything approaching a full realisation of its economic significance. It will be, in fact, a "First Class Pest" and its extermination cannot be hoped for; control measures in this case must aim at limiting its spread and mitigating its ravages as far as possible. It will be seen, therefore, that there are two main stages in the progress of an insect pest: firstly, when it is a newly established pest within a limited area, and secondly, when it has become firmly established and is widely distributed.

In the former case it may be possible to exterminate the insect, in the latter case it is only possible to control it.

The meaning and function of legislative control of insect pests is thus:

(*a*) To prevent the introduction and establishment of new pests from other countries;

(*b*) To prevent the further increase or spread of pests already established in the country itself.

Such legislation may be considered, therefore, as **external** and **internal** legislation. External legislation will include statutory orders against pests liable to be imported. Internal legislation will cover domestic enactments against established, or newly introduced pests within the country.

**External legislation** against insect pests may be laid down

either by International Agreement or individually by National Governments. As regards the former policy, whilst many countries enforce restrictive measures against importation of the same insect pest, international agreement on the part of several countries has been reached only with respect to the *Phylloxera* pest of the vine and with regard to locusts.

An International Phylloxera Convention was held on the 3rd November 1881 between a number of European countries. At that meeting the contracting States (Austria-Hungary, Belgium, France, Germany, Holland, Italy, Luxemburg, Portugal, Rumania, Servia, Spain, and Switzerland) agreed to restrict the movement of vines from one country to another. It was decided that vine stocks and cuttings can only be imported under Government Authority after proper disinfection. No restriction is placed upon the international movement of stocks, shrubs, and plants other than vines, but a certificate is required, issued by the authorities in the exporting country, to the effect that there has been no danger of *Phylloxera* infection.

The effect of this measure has been to limit the channels through which infested material might be introduced into a country, since importation is only allowed at certain points, through specified Customs Houses. It is obvious, of course, that the value of the agreement to the individual countries depends upon the thoroughness of the examination on the part of their own Inspection Service, but there is no doubt that this arrangement has done much to regularise and place the *Phylloxera* infestation in well-marked zones.

The International Convention for Organising Measures against Locusts met from the 28th to the 31st October 1920, at the International Institute of Agriculture at Rome. Twenty-six different countries were represented at that meeting, and it was agreed that the contracting States should take measures against locusts that were liable to cause an infestation in neighbouring signatory States and should also communicate any information as to the movement of such locusts. Provision is made for cases where States wish to co-operate in control measures. Further, the Contracting States agreed to forward all information bearing upon locust control, at stated intervals, to the International Institute of Agriculture at Rome.

To turn to the consideration of external legislation enacted by National Governments, it will be found that almost every country has its own lengthy list of insect pests which may not be introduced with imported goods. It is, of course, not possible on account of the limitations of space to examine, even quite generally, the various restrictive orders of different

countries. However, this type of legislation may well be illustrated by considering the measures enforced by various National Governments against importation of some particular commodity liable to infestation by certain pests.

As an example of a commodity which is widely distributed and is of great economic importance, **cotton** may be taken. Restrictive orders concerning the importation of cotton are aimed at the Pink Bollworm (*Gelechia gossypiella*), the Cotton Boll Weevil (*Anthonomus grandis*), and to lesser extent the Cotton Stainer (*Dysdercus* spp.), and Leaf Blister Mite (*Eriophyes gossypii*).

Such restrictive orders in the case of cotton are, of course, only found in countries which possess cotton-growing areas, since there can be no objection to the importation of cotton into such a country as Great Britain, where it is used merely for manufacturing purposes.

All the cotton-growing regions of the world will be found to be grouped roughly between latitudes 40° N. and 30° S. Of the world's cotton production the U.S.A. grows about six-tenths, India about two-tenths, Egypt about one-tenth, the remaining tenth being divided amongst the other cotton-growing regions.

In the case of the U.S.A. there is a restrictive Federal Order of April 27th, 1915, which prohibits the importation of cotton from all foreign countries except under permit. In the U.S.A. the special danger to be guarded against with regard to cotton is the introduction of Pink Boll Worm. Consequently, as indicated in Chapter XIV., unmanufactured cotton products have to be sterilised at the port of entry.

As regards Egypt, by Law No. 1 of 1916 (for the protection of plants against imported diseases) there is a specific prohibition against importation of cotton plants and seeds, cotton ginned and unginned, and cotton wool.

In India, by the Destructive Insects and Pests Act of 1914, there is a general prohibition against the importation of any article liable to infect any crop. By a further Government Order of 1917, no plant is to be imported to British India except fruits, vegetables, and sugar-cane unless sterilised with hydrocyanic acid gas at one of the specified ports.

Of other Cotton countries, the Australian Commonwealth by the Quarantine Proclamation of May 6th, 1922, enforces a specific prohibition of the Pink Boll Worm.

In the West Indies, orders by various authorities prohibit the importation of cotton seed, etc., into Barbadoes, Trinidad, Tobago, St. Vincent, St. Kitts, Nevis, and Antigua.

It will be seen, therefore, that countries containing cotton-

growing areas have laid down drastic regulations to prevent the introduction of insect pests of cotton; and, generally speaking, it will be found that all countries which grow crops liable to heavy infestation by particular insect pests have either a specific or a general restriction order against the importation of such pests. Importation of plants and plant products is usually only permissible when accompanied by a foreign inspection certificate or after subjection to sterilisation at the port of entry. In the case of many commodities, cotton, for example, National Governments do not rely upon any protection which might be gained by certification or by inspection at the ports, but demand that such products shall in no way come into contact with their cultivated areas.

An ideal system of legislative protection against the possible importation of insect pests should provide for:

1. Inspection of the crops of the importing country when growing. The official entomologists of the importing country should have full information on this point.
2. Certification as to freedom from pests of all plant shipments, carried out by competent entomologists at the port of departure.
3. Fumigation certificates issued at the port of departure.
4. Inspection of shipments at the port of arrival.
5. Fumigation on arrival.
6. Quarantine of certain plants.
7. Prohibition.

In actual practice the most effective system is that of inspection on arrival, carried out by a fully competent staff in a well-organised plant inspection station, somewhat on the lines of the one at Hamburg; the inspection should be supplemented by certificates of inspection or fumigation issued at the port of departure, and by quarantine measures (Vuillet, 1913).

**Internal legislation** against insect pests may be enacted by (*a*) National or Federal Governments and by (*b*) Provincial or State Authorities. In such countries as the U.S.A., Canada, or Australia, where each province or state possesses a large measure of self-government, there will thus be two kinds of internal legislative measures, namely, *Federal* and *Inter-state* regulations laid down by the Central or Federal Government, and *Provincial* or State regulations laid down by the Provincial Authority. Internal Federal Quarantine in the U.S.A. is limited to inter-state control; that is to say, the Federal Government does not legislate for insect infestations within the borders of one State except where such pests are liable to

spread to other States, but makes regulations between States or covering several States. Thus, since the State Authority itself can lay down regulations for State Quarantines and can also declare quarantines against neighbouring States, it follows that while the Federal Government may put into force regulations affecting any part of the country, it acts in practice rather in an advisory capacity to the State authorities upon matters of internal legislation.

As an instance of the various problems involved in the question of internal legislation the case of the European Corn Borer (*Pyrausta nubilalis*) may be taken, a pest of maize in the U.S.A. and Canada. This pest is prevalent, as regards the U.S.A., in the States of Massachusetts, New Hampshire, New York, Pennsylvania, Ohio, and Michigan; in Canada it occurs in Ontario Province around the shores of Lake Ontario.

In Canada, apart from external legislation (Amendment No. 15, 1922, to Regulations under Destructive Insects and Pests Act) which prohibits importation of maize and other host plants of the European Corn Borer from specified districts in the United States, the pest is dealt with by Quarantine No. 2 of 29th November 1920, whereby certain areas in the Province of Ontario are scheduled and the movement of maize and maize products in these areas restricted.

In the United States, by Federal Order (Quarantine 43), a quarantine is declared prohibiting the movement from infested areas in the States of Massachusetts, New Hampshire, New York, and Pennsylvania of any maize or maize products or other host plants of the Corn Borer, except under permit. In addition to this measure, the various States concerned have their own restrictive orders enforcing a quarantine of certain infested districts in their own territory.

The inspection methods of the State authorities are of particular interest. For example, in Massachusetts, where the infestation is severe, maize and other host plants, such as celery, beet, and spinach, if grown in a quarantined district may not be moved from that district unless accompanied by a certificate of freedom from infestation. These crops may be sold inside the scheduled area without further formality, but since a price lower than elsewhere prevails, there is a great demand for inspection certificates in order that crops may be sent to outside markets. Owing to the large quantities of material requiring inspection and the thoroughness of the inspection methods, a large body of inspectors is necessary for this duty alone.

When the crop requiring inspection has been gathered it is conveyed to the barns or storehouses, and a crew consisting

of a foreman and about six men of the Inspection Service examine minutely each plant. After the inspection a tag is given for attachment to each package, and this forms a clearance certificate. Inspection of growing crops is also undertaken. If the field after examination of each plant is found to be uninfested, sufficient tags are given for the calculated amount of crops.

One of the practical difficulties in carrying out this quarantine is that of preventing motor-cars, whose passengers may have sweet corn, etc., as provisions, passing out of the scheduled district uninspected, and there is the possibility that infested material may thus be carried to clean areas.

The reluctance of Governments to accept foreign certification, or even to rely upon inspection at the port of entry in the case of important products, indicates to some extent that in practice legislative measures based on inspection are not to be regarded as entirely effective. There are, in fact, serious weaknesses both in certification and inspection methods.

Taking the question of certification, it is clear that to allow the importation of plants and plant products without further limitation than that afforded by a foreign inspection certificate is to place too great reliance upon the thoroughness of the examination carried out by the Inspection Service of the foreign country. Such certification has been frequently proved to be unreliable. Morrill (1913), observing that practically all State Horticultural Laws in the U.S.A. require a certificate of inspection from the shipper's home State as a condition of acceptance of nursery stock importations, asserts that this requirement fails in its object. His experience in those States where shipments are inspected on arrival is that 9 per cent of certificated shipments were infested. According to Saunders (1914), practically all the Western United States, including Montana and Colorado, refused to accept Eastern certificates and insist on re-inspection of incoming material at the place of delivery. Other States insist upon fumigation of imported nursery stock prior to acceptance.

As regards inspection methods, O'Byrne (1921) declares that in the United States inspection alone will not give proper protection. Owing to the fact that the nurseryman has a large amount of capital invested in his business, it is difficult even if a pest be discovered to condemn the whole of the stock, since he would probably take legal action and win the case.

The inspector is also helpless when dealing with a new pest. It is not possible to put a blanket quarantine, which might damage or ruin the nurseryman, when only slight infestation is found. Then, again, detection of disease in its initial stages

is difficult, since after infection there is always an inoculation period during which there may be scarcely any sign of infestation. The very best inspection service, in fact, will stop only the most severely infested stock.

In this connection, attention may be drawn to the fact that in England a legal obligation is laid upon farmers to report the occurrence of certain pests, termed Scheduled Pests, on their crops or stock to the Ministry of Agriculture through the channel of the local police. It is, of course, quite clear that without some such system of notification the inspection service, being without adequate appropriations, would actually become almost a dead letter. At the same time, the weakness of the system is that the farmer is generally unable to recognise infestation in its initial stages, so that such insect outbreaks have every opportunity of becoming widespread before the attention of the Ministry of Agriculture is drawn to them.

Apart from these difficulties in the actual operation of legislative measures, such legislation is often put into operation too late to give it a fair chance of proving effective. As Felt (1920) has pointed out, it is very difficult to secure a general unanimity of opinion as to the economic status by any particular pest before it has spread to a material extent and caused serious losses. Such delay gives the insect an opportunity to multiply, and if reasonably active and prolific it may, within a season or two, increase beyond all reasonable possibilities of control.

In conclusion, the following quotation from Headlee (1915) sums up the position and aim of legislative control:

"Little by little many injurious species are widening their distribution. It is probably only a question of time until their range throughout the world will include all regions where food conditions are favourable and climate bearable. The delay in their distribution, which it seems practicable to effect through control measures, seems likely to prove sufficient for their new environment to become adapted to them and for the natural enemies which attack them in their own homes to become distributed in their new ones, thereby reducing them to the position of the pests native to the country into which they have migrated before they had a chance to do great damage.

"The work of preventing the establishment of seriously injurious insects is far more effectively done than is the work of controlling the outbreaks of already established species. Year out and year in the standard pests of the country gather headway in some parts of their range and do damage."

# APPENDIX

## MACHINERY

THE large scale upon which Horticulture and Agriculture are carried out at the present time, and the ever-increasing attention that is now being paid to the question of Insect Control, have stimulated the invention of what may be termed Insecticidal Machinery to a remarkable degree. There are in the U.S.A. at least a dozen prominent firms manufacturing nothing but Spraying and Dusting machinery and accessories and exporting their products all over the world ; in Great Britain there are quite half-a-dozen such firms ; other countries, such as Canada, France, Germany, are also represented in this industry. Such machinery naturally is always in a transitory condition, established types being constantly improved upon or replaced by superior models, and this continual flow of improvement and replacement somewhat invalidates any definite expression of opinion as to the respective values of different mechanical types. Any discussion of Insecticidal Machinery has necessarily to be limited to the underlying principles of construction and to the general trend of development.

Nor can it be said that there has been an equal degree of progress in all branches of the subject. In the past, mechanical ingenuity has been lavished upon Spraying Machinery ; Dusting Machinery has received less attention ; Sterilisation Machinery (Hot-air machines) and Fumigation Machinery have scarcely progressed beyond the experimental stage.

The application of insecticides in liquid form is carried out by Spraying Machines. The application of poisonous substances in a dry condition, as dusts, is carried out by Dusting Machines. Unfortunately the term " spraying " is often used to describe the application of dusts, so that it is desirable for the sake of clearness to draw a terminological distinction between Wet and Dry spraying and to confine the use of the expression " spraying " to the employment of Wet Sprays.

Consideration of the various types of apparatus used in spraying may well be dealt with under four headings: (*a*) **Hand Sprayers,** (*b*) **Traction Sprayers,** (*c*) **Power Sprayers,** (*d*) **Machine Accessories.**

**Hand-spraying,** which depends upon manual power for its operation, can be carried out by various types of hand sprayer.

There are the *Syringe, Bucket, Knapsack, Compressed Air, Barrow, Barrel,* and *Horizontal Tank* types of machine. The kind of hand machine selected will depend very largely upon the quantity of spraying that has to be carried out.

*Syringe Sprayers,* which are the usual garden syringes fitted with a special spraying nozzle, can be used very conveniently for small greenhouse work. Their limitation is that they are suitable only for spraying a few plants at a time; their small capacity would otherwise involve too much time and labour.

The *Bucket Sprayer* consists of a small hand pump used in conjunction with a bucket. The pump may be attached to the inside of the bucket, or may be a separate unit with a pedal attachment to increase its stability (Fig. 15).

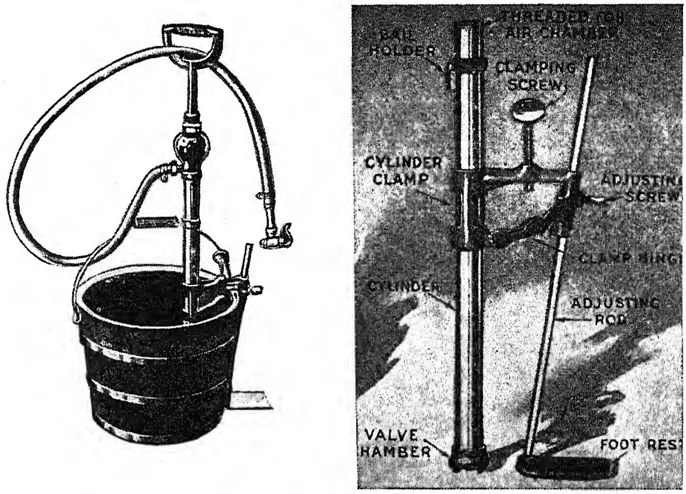



FIG. 15.

The bucket sprayer is much used for spraying small trees, garden crops, flowers, and shrubbery; or for applying limewash and disinfectants to barns, shippons, poultry houses; or for applying dips and repellents (fly oils) to live stock.

The *Knapsack Sprayer* consists of a small tank holding about three gallons, which, as the name implies, is slung by straps from the back of the operator. There are two types in use, one with an internal pump (*Vermorel pattern*), the other with external mechanism (Figs. 16 and 17).

Both patterns are operated by means of a handle, which is placed at the side of the tank convenient to the right hand of the operator. Of the two types, the external pump pattern is considered in practice to be the more suitable, owing to the greater accessibility of the pump parts for examination or replacement.

The knapsack sprayer is chiefly used in small orchards and vineyards and is very popular in France.

*Compressed Air Sprayers* (Fig. 18), consisting of a small portable cylinder of about one to three gallons' capacity fitted with a hand-operated air-pump and pressure gauge, are the most recent developments in hand sprayers. After the spray fluid has been placed in the cylinder


FIG. 16.

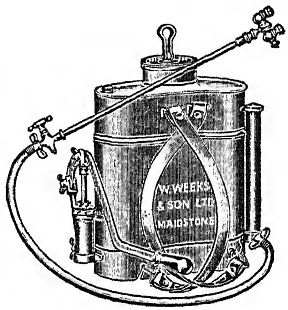



FIG. 17.

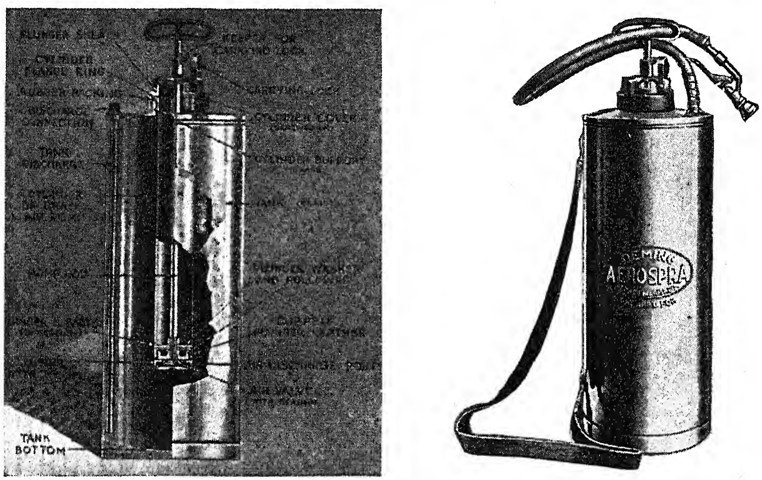



FIG. 18.

it is put under pressure by about a dozen strokes of the air-pump. The spray can be released by pressure upon a small lever attached

to the handle, and will emerge as a fine misty spray for several minutes without the necessity for further pumping.

Compressed air sprayers are quite as efficient as bucket and knapsack sprayers and they possess obvious advantages over them. They are less laborious to operate, the worker has both hands available to control the spraying hose, and a more constant and greater pressure, about 100 lbs. per square inch, in fact, is obtainable than with the ordinary manual pump. It is probable that in the future they will almost entirely supersede the bucket and knapsack types.

The *Barrow Sprayer* (Fig. 19) has a capacity of 10 to 50 gallons, and is just a small tank or barrel, mounted upon one or upon two

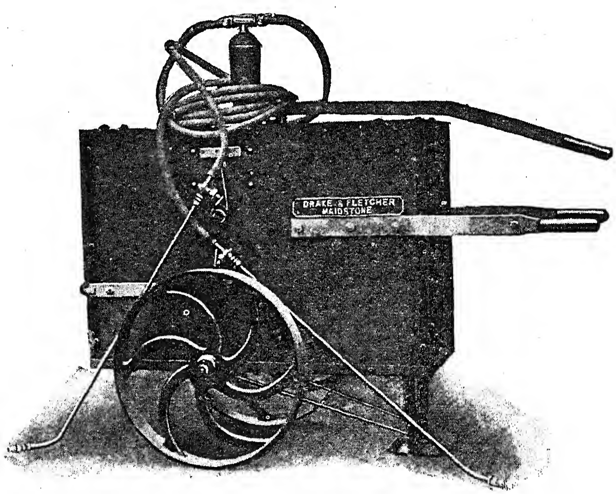



FIG. 19.

wheels, and possessing a hand-pump attachment. Several lengths of hose and lances, or extension rods, complete the equipment. This machine, a popular type in Great Britain, is very suitable for small orchard and garden work.

The *Barrel Sprayer* (Fig. 20) consists of a 50-gallon barrel fitted with a hand-pump, and is used especially by farmers in U.S.A. owing to its general utility. It can be used for orchard-spraying by attaching lances, or it can be operated from an ordinary farm waggon, and if provided with a series of spray-booms will treat field crops very efficiently.

The *Horizontal Tank Sprayer* is similar in type to the barrel sprayer, the main difference being the substitution of a cylindrical 100-gallon tank for the barrel. It is suitable for small orchards, for plantations, and for farm-spraying work generally.

The barrow, barrel, and tank sprayers should possess an air-chamber attachment to the hand-pump, so that the operator can rest between strokes without any pressure being lost. Such an air-chamber permits a higher pressure, about 150 lbs. per square inch, being obtained than with the ordinary design of pump.

It may be noted that the pump-action in these machines may be of different types. The pump may be worked by vertical, horizontal, or rotary motion; the backward and forward movement of the horizontal type is less fatiguing than the upwards and downwards motion of the vertical action.

**Traction-spraying** is intermediate in character between hand- and power-spraying, a medium pressure of about 175 lbs. per square inch being obtainable. Traction sprayers usually have a tank capacity

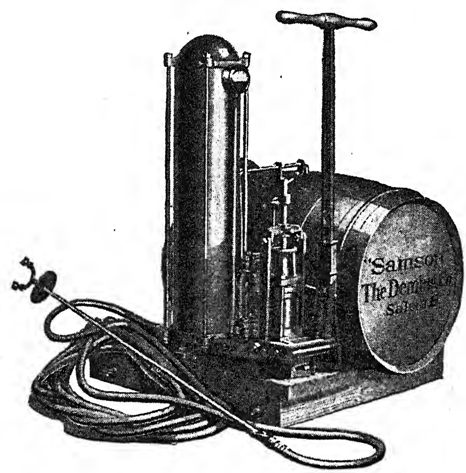


FIG. 20.

of 50 to 100 gallons, and tank and pump are mounted on a horse-drawn framework in such a way that the pump is worked by gears, or by chain-drive from the travelling wheels (Fig. 21).

This type of machine fitted with a spray-boom is admirable for the spraying of field crops. It can be used under conditions where a power sprayer is out of the question. On the other hand, it cannot be used for orchard work, owing to the dependence of the pump-action upon the vehicle being in motion, unless the pump be fitted with an independent engine attachment. Such an attachment converts the sprayer into a light power machine, since the pump can be operated whilst the vehicle is stationary, and a pressure of about 200 lbs. per square inch can be obtained.

**Power-spraying.**—When large-scale spraying is necessary, some form of power sprayer is indispensable. There is greater economy

of time and labour, a greater amount of spraying carried out in a given time, a higher and more uniform pressure obtained, and a consequently greater efficiency of results.

The types of Power-spraying Machines at present on the market can be divided into three groups: (1) Small, (2) Medium, and (3) Large Power machines. No uniform grading has been adopted by manufacturers. Some firms rate their machines at a capacity in gallons per minute at a given pressure, others by the horse-power and the number of gallons supplied per minute. Other firms, again, attempt to express the capacity of their machines by the number of nozzles or spray-guns supplied, or by the number of lines of hose that

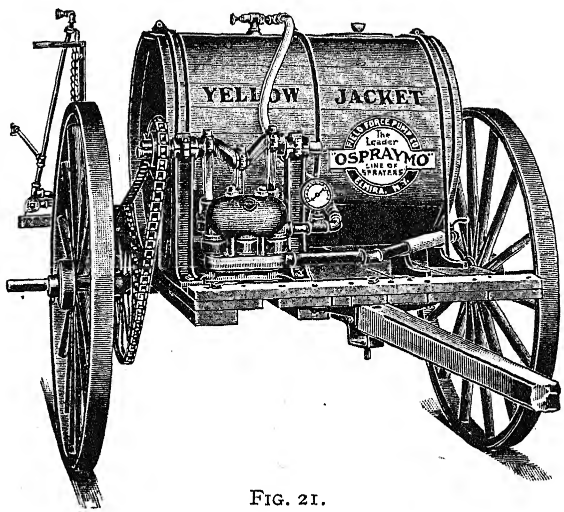



FIG. 21.

can be worked; both these latter gradings are unscientific, since there is no standard of size for nozzle or spray-gun.

Speaking generally, the capabilities of different grades of machines are as follows:

| Type. | Horse-power. | Gallons per Minute. | Pressure in Lbs. per Sq. Inch. |
|---|---|---|---|
| Small Power . . | 1–2½ | 2–5 | 150–250 |
| Medium Power . | 2½–5 | 5–12 | 250–300 |
| Large Power . . | 10–60 | 15–50 | 300–800 |

Power sprayers are mounted upon a horse-drawn framework or upon a motor truck. In the largest power machines the pump may

be operated from the truck-engine or from an independent motor attachment.

Difficulty is often experienced in deciding between a small or a higher power machine. As a general principle, a machine of rather higher power than is required is preferable to one that is too small, but it is useless to purchase a power machine that is apparently cheap. It is better for the farmer or horticulturist to co-operate with other cultivators in buying good but expensive machines.

The *Small Power Machine* type (Fig. 22), consisting of different outfits varying from 1 to 2½ h.p., supplying 2 to 5 gallons per minute at a pressure of 150 to 250 lbs. per square inch, with tank capacities

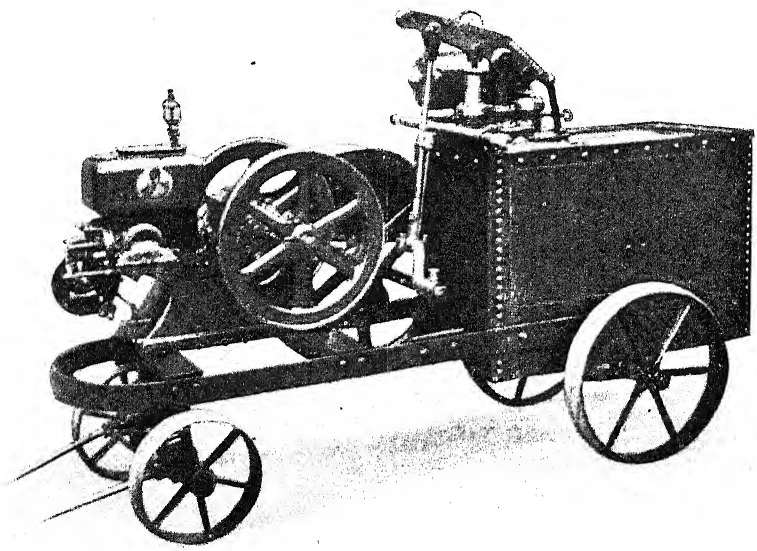


FIG. 22.

of 50 to 150 gallons, finds its chief use under conditions where a hand-operated machine is too laborious to use. It is very suitable, in fact, for small orchards or for disinfecting or limewashing farm buildings.

Where fairly large capacity but not too great a pressure is required, the *Medium Power Machine* type (Fig. 23) of different units ranging from 2½ to 5 h.p., giving 5 to 12 gallons per minute at a pressure of 250 to 300 lbs. per square inch, with tank capacities of 100 to 250 gallons, will prove very useful. The medium power sprayer will treat large orchards and hop-gardens very effectively.

If it is necessary to spray a large acreage, or if a number of tall trees have to be sprayed, then a *Large Power Machine* is the only apparatus which can be relied upon to supply the necessary pressure.

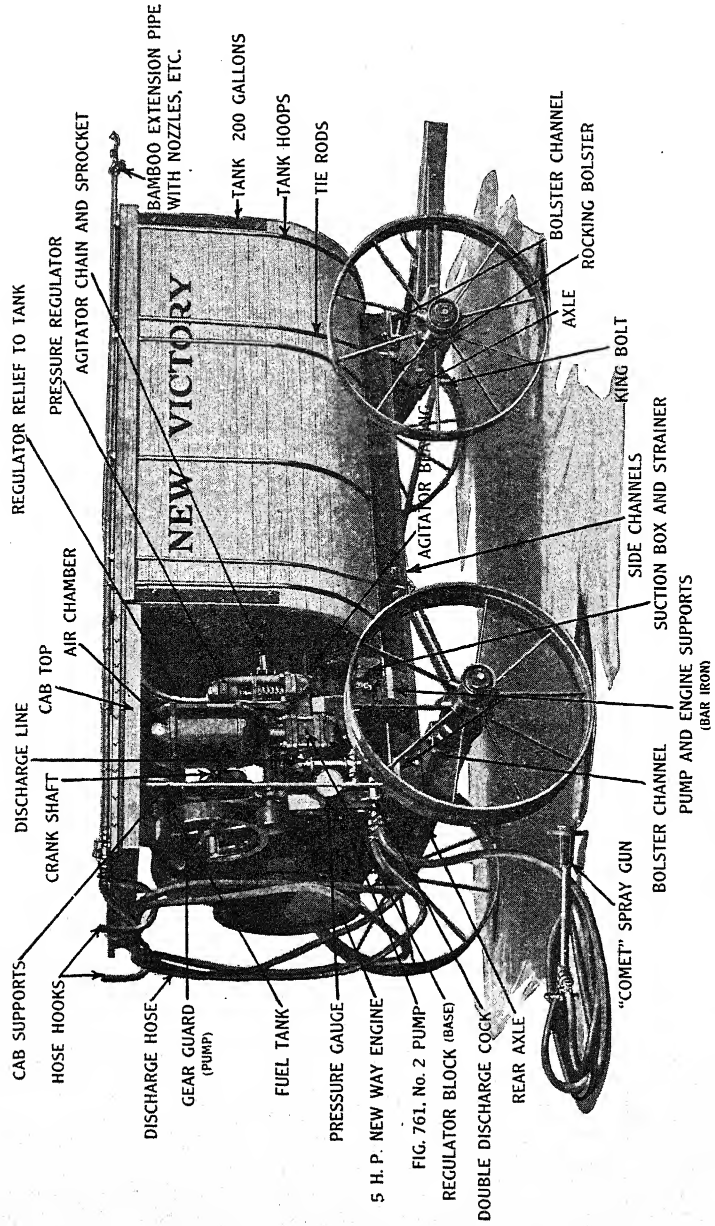

BAMBOO EXTENSION PIPE WITH NOZZLES, ETC.
TANK 200 GALLONS
TANK HOOPS
TIE RODS
NEW VICTORY
AGITATOR CHAIN AND SPROCKET
PRESSURE REGULATOR
REGULATOR RELIEF TO TANK
AIR CHAMBER
CAB TOP
DISCHARGE LINE
CRANK SHAFT
CAB SUPPORTS
HOSE HOOKS
DISCHARGE HOSE
GEAR GUARD (PUMP)
FUEL TANK
PRESSURE GAUGE
5 H. P. NEW WAY ENGINE
FIG. 761, No. 2 PUMP
REGULATOR BLOCK (BASE)
DOUBLE DISCHARGE COCK
REAR AXLE
"COMET" SPRAY GUN
BOLSTER CHANNEL
PUMP AND ENGINE SUPPORTS (BAR IRON)
SUCTION BOX AND STRAINER
SIDE CHANNELS
AGITATOR B
KING BOLT
AXLE
ROCKING BOLSTER
BOLSTER CHANNEL

FIG. 23.

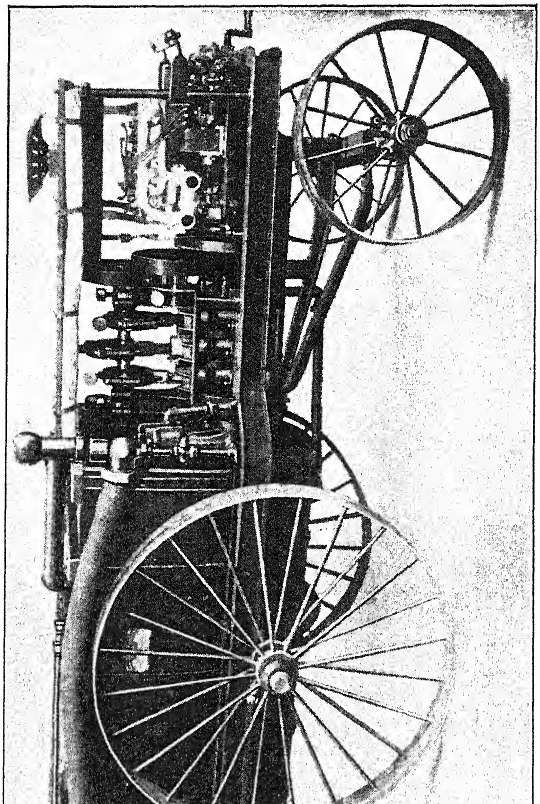


FIG. 24.

Such a machine is a necessity also where a large amount of spraying has to be carried out in the minimum of time, where the vulnerable stage in the life-cycle of the pest is of very short duration. There are really two kinds of large power machines. For ordinary commercial orchard work, not usually involving the spraying of high trees, a suitable power sprayer will be of about 10 h.p., giving approximately 20 gallons per minute at a pressure of 300 lbs. per square inch, with a tank capacity of 300 gallons (Fig. 24).

The other type of large power sprayer has been appropriately termed "High Duty Apparatus," and is used in connection with what is called "Solid Stream Spraying." In an ordinary spraying machine the spray nozzle is fitted with some kind of mechanical arrangement in its orifice so as to break up the emerging jet of liquid into a fine mist; such a spray-jet is not effective beyond 16 feet, so that to spray really high trees the use of ladders or spray-towers is necessary. By using a special kind of nozzle, however, which does not break up the jet, and by using a very high pressure, the jet of liquid can be forced up into the air to a considerable height as a solid stream before breaking up into a spray. The fineness of the spray will depend upon the force of pressure behind it. Since at least 300 lbs. per square inch is necessary at the nozzle, a considerably greater pressure at the pump is required to overcome the friction-resistance of pipe-lines and hose. To provide such high pressures, special machines are constructed and marketed. The power-spraying machines used by the Federal and State Authorities of the United States in the Gipsy Moth Control Work are of this type. They are carried upon 60 h.p. motor trucks, 2½ to 3 ton weight type, and have a tank capacity of 400 gallons. The pump is of the single-acting, triplex plunger type, with cylinders of 3½-inch bore and 4-inch stroke, and is driven from the main drive shaft, the drive being capable of transmitting the full engine-power; the delivery is 50 gallons per minute at a pressure of not less than 600 lbs. The sprayer attachment is detachable, so that the truck can be used for general transport purposes (Fig. 6). The same apparatus is also made as a complete unit with a 35 h.p. engine, mounted upon a skid so as to slide into any motor truck body.

Owing to the impossibility of driving motor trucks close to the trees in thickly wooded or mountainous districts, it has been found necessary in some localities to use almost a mile of pipe and hose, and a pressure of 800 lbs. at the pump is required in order to develop a pressure at the nozzle of 250 lbs. per square inch, owing to the friction-resistance of this length of piping.

The **Machine Accessories** are quite as important as the components of the machine itself, since upon their efficiency depends the success of the whole spraying operation. These accessories are the *nozzles*, *lances* or extension rods, *spray-guns*, *spray-booms*, *stop-cocks* or cut-offs, *hose and pipe-lines*.

Of these accessories, the most important is without doubt the

*nozzle* (Fig. 25). Among users of spraying apparatus there is far from complete agreement concerning the best type of nozzle to use. It must be understood that in a spraying operation there are two important requirements which are affected by the character of the nozzle. These are (*a*) the production of a fine misty spray, and (*b*) a high pressure or force of penetration. The finer the spray and the greater this force of penetration, the more effective the spraying operation. The difficulty, of course, is to obtain these two conditions simultaneously. By making the nozzle aperture smaller, a finer spray will be obtained, but the force of penetration will be lessened. On the other hand, the larger the aperture in the nozzle, the greater will be the pressure of the spray-jet, but the spray will be coarse and cover the sprayed object less evenly.

Then, again, the type of spray required against a biting insect differs somewhat in its requirements from that used against a sucking insect. In the case of a Stomach Poison, only sufficient to cover the leaves is required; the liquid should not be in such excess that it drips from the foliage. In the use of a Contact Poison, such excess is not such a serious matter, since the paramount requirement is thorough wetting of the insect pest.

Speaking generally, the various types of nozzles on the market belong to one or other of two types. Either they are designed to produce a flat, fan-shaped jet, or they produce a conical jet, that is to say, a hollow cone of water particles.

The type of fan-producing nozzle is the *Bordeaux*, in which the stream of fluid is allowed to strike against a lip which breaks it into a fan-shaped jet. The fineness of the spray is governed by the width of the exit aperture. If the nozzle gets blocked, it can be readily cleaned by reversing the cut-off, thus allowing an unbroken stream of liquid to pass through it. It is a very suitable type of nozzle, therefore, for applying Bordeaux Mixture, lime-wash, or any spray fluid containing much suspended matter. A great advantage is that the jet can be changed gradually, by turning the cut-off, from a solid stream of liquid to a misty spray. Where the jet has to be forced straight into blossoms, there is a greater economy of liquid in using the Bordeaux type of nozzle than with a nozzle giving a cone-shaped jet.

One objection, however, to this type of nozzle is that the jet is oval in section, so that the water particles are fine and misty at the edges but comparatively coarse in the centre. Woodworth (1916) has suggested the use of a nozzle which allows two streams of liquid to impinge upon one another in such a way that the jet produced is in a plane inclined at an angle of 45 degrees from the plane of the impinging streams. He claims that the jet produced is very flat, of uniform thickness throughout, and breaks up into drops of great fineness and uniformity.

The standard type of nozzle giving a cone-shaped jet is the *Vermorel*. It consists of a small chamber into which the liquid

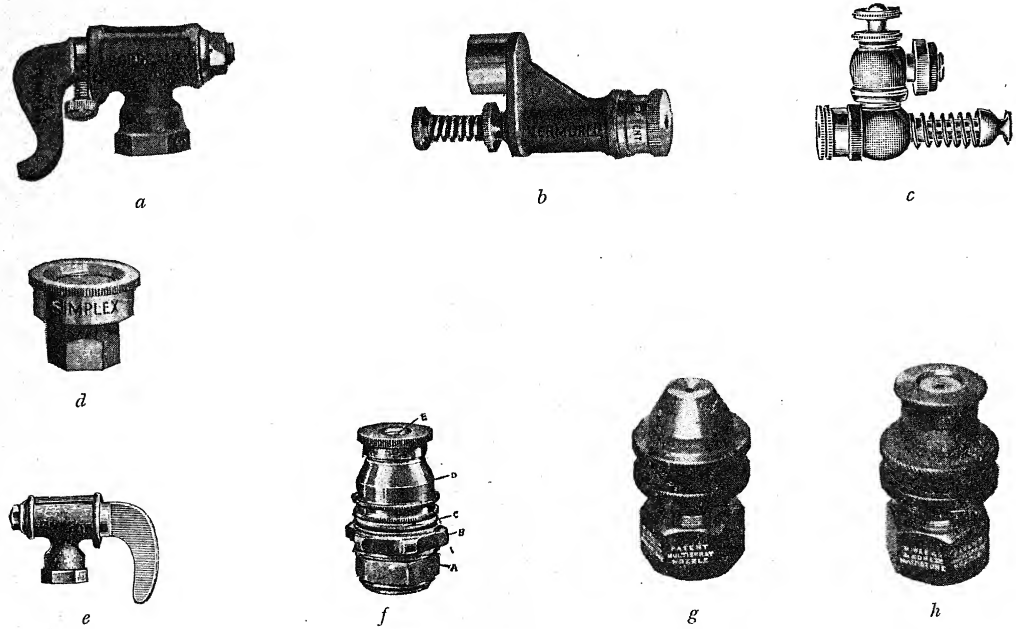



FIG. 25.—Nozzles: (*a*) "Bordeaux"; (*b*) and (*c*) "Vermorel"; (*d*) "Simplex"; (*e*) "Seneca"; (*f*) "Mistifier junior"; (*g*) and (*h*) "Multi-spray."

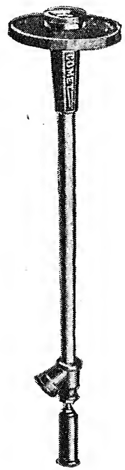


FIG. 26. Spray-gun.

is admitted at a tangent and escapes through a small hole in a removable cap. A small pin, held back by a spring when not in use, serves as a " degorger " to remove any sediment which may lodge in the outlet. In this type of nozzle the stream diverges widely in the shape of a hollow cone, consisting of a very thin sheet of liquid, which breaks up into a uniformly fine mist. This fine and uniform spray is very useful where an even covering of the foliage is required, but when it is necessary to spray at a definite mark, such as a branch, there is waste of liquid, since the ring of spray is apt to surround, instead of touching, the object at which it is directed.

An improvement upon this type of nozzle is the *Disk* type, made by various firms, in which the chamber is made broader and flatter, with a large exit aperture. No degorger is required, since the large aperture prevents clogging and a much larger volume of liquid can be passed through the nozzle.

There are many other types of nozzle. In fact, nearly every manufacturer has his own design as well as modifications of the Bordeaux and Vermorel types. Thus the *Cyclone* type, made by several firms, supplies a conical jet similar to that of the Vermorel, but has no degorging device. The *Seneca* type of nozzle is a modification of the Bordeaux, and so on. The general principle of most nozzles is the introduction of baffles inside the nozzle in order to break the rotation of the liquid in the hose, and then, by placing discs with apertures of various sizes within the cap of the nozzle, to break up the jet more or less finely. One very effective design, for example, consists of an adjustable nozzle which is fitted with an outer cap made to hold one or more discs of different sized apertures. A collar screws up and down the stem and controls the amount of spray passing through the nozzle. If a strong but relatively coarse jet is required, the collar is screwed up to the tip of the stem and a disc with a large aperture is placed in the cap. When the collar is screwed down and a disc with a small aperture used, a fine misty spray is obtained. A medium spray will, of course, be obtained by adjusting the collar to an intermediate position and varying the size of the aperture in the disc.

In " Solid Stream Spraying " the type of nozzle used differs in principle from the types described above. The jet is not broken up by the use of discs at the nozzle, but the unbroken spray-jet impinges upon a flat piece of metal, the " Spreader," fitted to the side of the nozzle, and the fluid is carried up to a great height by the high pressure behind it before it breaks up into a fine spray.

The *lances* or extension rods, to the ends of which the nozzles are fitted, are used to bring the spray-jet closer to the foliage of the higher portions of the trees that are being sprayed. The lance, consisting of a brass or aluminium $\frac{1}{4}$-inch piping, or bamboo pole, is held in the hands of the operator and directed so as to spray all the foliage. Since the nozzle attachment usually comprises a swivel joint, the jet may be directed downwards or in any other

plane of direction. Lances are often made of bamboo fitted inside with thin metal tubing. The lengths of rod can be joined together and to the hose by couplings.

The *Spray-gun* (Fig. 26) is a device recently introduced to obviate the tedium and labour of holding up a lance for long periods. Spray-guns are made in several designs, but are all lighter and much shorter than extension rods, and give an immediate adjustment of spray by means of a rotatory handle. Foliage near to the ground can be treated with a fine mist, and then, by turning the handle, greater pressure is obtained and the tops of the trees can be reached.

The increase of pressure required to force the spray to a height would seem, however, to coarsen the spray, so that the upper foliage is less evenly coated than would be the case if sprayed from a lance. It is not possible, also, to spray downwards upon the foliage, as can be done with a lance fitted with an angle-nozzle, and further, the spray-gun cannot be used with every type of machine, since a reserve of pressure is necessary; a machine of at least 10 h.p. is required to supply two guns.

*Spray-booms* (Fig. 27) are used for the spraying of field crops. They consist of a series of pipes extending to a width of about 16 feet, attached to the back of the machine. The spray fluid circulates through them *via* connecting hose from the tank on the machine. An extended spray-boom allows a number of rows of the crops to be sprayed at one time. Provision is made for the boom to fold, so that farm gateways can be negotiated.

It is scarcely necessary to point out that *stopcocks* or cut-offs are essential accessories to a spraying machine, to prevent waste of fluid. A stopcock fitted to a lance should be so placed that the operator can cut off the supply of fluid without altering his distance from the nozzle. A suitable type of stopcock is made of brass with a stuffing box which can be tightened to prevent leakage. The stopcock should be provided with some form of cut-off handle, so as to be operated by one movement of the hand.

The use of the best grade of *hose* is advisable, not only because it will last longer than one season, but because the use of poor hose leads to a lower pressure being used than the machine is capable of, in order to prevent the hose leaking. Three-ply and four-ply are the qualities usually used, but for high pressure five-ply or even six-ply is advisable.

*Pipe-lines* may be necessary in orchards and hop-gardens where the cultivation is so close that it would not be possible to drive a machine through, or where the ground would not support the weight of a machine. Either permanent mains are laid down, or portable lengths of light galvanised iron piping fitted with suitable couplings are used. The piping must not be less than 1 inch in diameter, owing to the friction set up and the consequent loss of pressure. The machine is placed at a point convenient to the water-supply, and sufficient pressure to force the fluid through the piping and up the

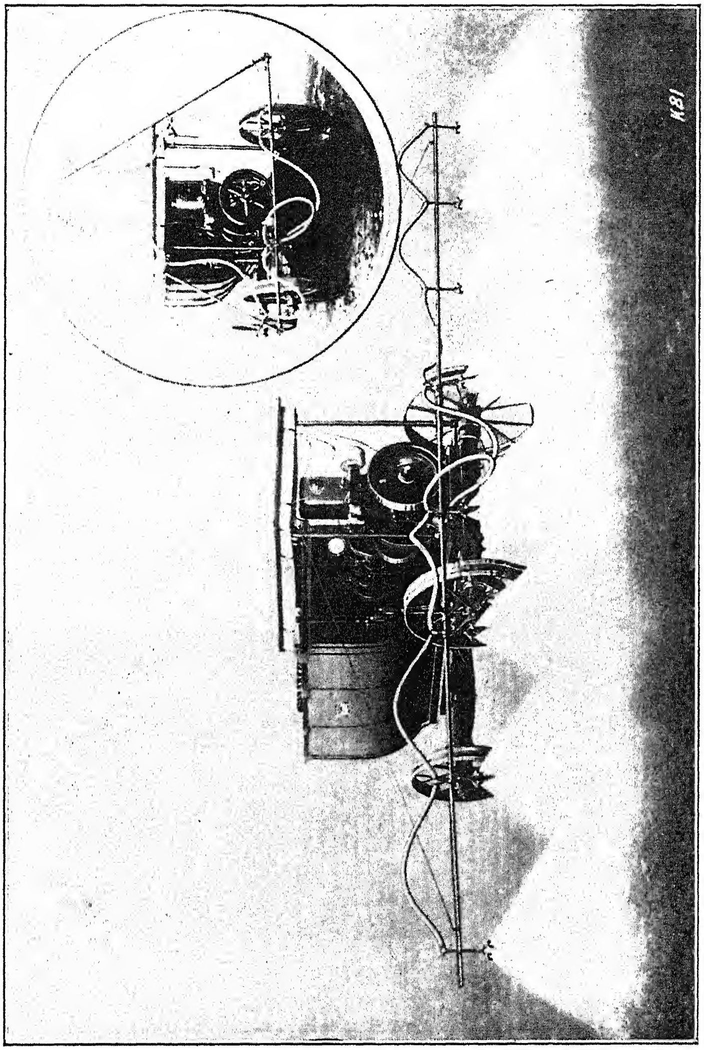


Fig. 27.

hose is necessary. The pipes are provided at intervals with stop-cocks to which hose can be temporarily fitted and the foliage in that section sprayed.

In conclusion, in deciding upon the purchase of a spraying machine the following points should be carefully considered:

1. The machine, and especially the pump and valves, should be of an efficient design.
2. An air-chamber attachment to the pump should be provided in order to keep the pressure constant, and a suitable relief valve should be fitted into a power machine to prevent the pressure becoming too high when the nozzles are cut off.
3. A satisfactory agitator should be fitted within the tank, so as to keep the fluid well mixed.
4. Nozzles, pump, and tank should be constructed of non-corroding materials.
5. All parts of the machine should be easily accessible, so that the packing of pistons, glands, stuffing boxes, can be easily renewed, and the various parts cleaned, adjusted, or replaced.
6. Spare parts should be easily obtainable.

### Dusting Machines

Dusting machinery may, like spraying machinery, be conveniently divided for discussion into (*a*) **Hand Dusters,** (*b*) **Traction Dusters,** and (*c*) **Power Dusters.**

**Hand-dusting** is a somewhat tedious operation, but is feasible,

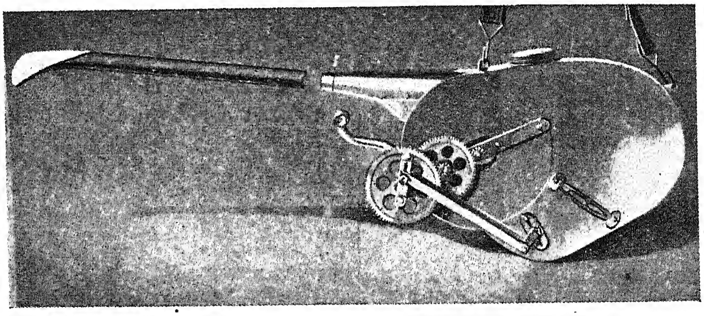


FIG. 28.

economically, for areas not exceeding 8 acres. There are two types of apparatus.

The *Hand-gun* (Fig. 28) is slung by straps from the shoulder so as to hang by the side or rest on the abdomen of the operator; it is made of sheet metal and comprises usually a dust-receptacle or "hopper," a fan arrangement, and a feeding mechanism.

The particular machine figured has a fan action worked by a crank-and-gear arrangement at the side. In some designs the dust is delivered into the air passage in front of the rapidly rotating fan; in others the fan works directly in the dust and forces it out through the air passage into the discharge pipe. When the dust is fed into the air passage through holes or slits in the hopper, so as to provide a gravity feed, some difficulty is experienced with the dust that accumulates in the air passage when the fan is stopped; it either chokes up the passage or becomes blown out later in lumps. With a brush feed, also, there is the disadvantage that in certain types the brush will dig out a cavity in the dust and so stop delivering it unless some form of agitator be provided.

The capacity of the hand-gun is 5 to 10 lbs. of dust, and it will cover about 1 acre per hour.

One design of gun is intended for use on horseback. The apparatus rests on the saddle in front of the rider, so that he can operate the duster whilst riding down the crop rows in the field. There are two discharge pipes, directed downwards and backwards, one on each side of the rider, so that two crop rows can be dusted at once.

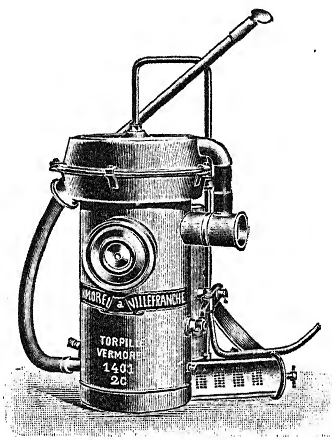



FIG. 29.

For operations on a large scale the hand-gun is, of course, unsuitable, but has, however, a certain value for the treatment of awkward places, or corners inaccessible to the power duster.

The *Knapsack Duster* (Fig. 29), which is slung from the back of the operator in a similar manner to the knapsack sprayer, has a bellows action, actuated by the raising and lowering of a handle at the side of the machine, the bellows being placed at the top or at the side of the dust-container. The bellows action may be single or double, the latter giving a more even blast.

So far knapsack dusters have not shown themselves to be very efficient in the field, the volume of dust delivered being usually inadequate and not continuous in its action; consequently it would seem doubtful whether the bellows action is mechanically sound from a practical point of view.

**Traction Dusters** resemble traction sprayers in that the motive power is derived by gears, or chain-drivers, from the travelling wheels, and in being intermediate in capacity between hand and power dusters.

In the usual type of traction duster, a revolving fan driven from the wheels provides an air-blast which blows out the dust, delivered

into the discharge pipe by a brush-feed, or auger-feed, from the hopper. The discharge pipes end in flattened funnel-shaped mouthpieces and spreaders.

The traction duster is very suitable for dusting field crops, the machine being light and controllable by one man; the dust is evenly distributed, and the quantity of dust delivered can be regulated by the speed of driving the vehicle.

Dusting with calcium arsenate has been tried extensively against the Cotton Boll Weevil (*Anthonomus grandis*) in the southern United States. Two types of traction dusters are in use. There is a one-horse machine having one wheel like a barrow, the operator walking behind the machine. From the hopper, two nozzles project backwards, one on each side of him. The machine has a capacity of 60 lbs. of dust, will generally dust three rows of cotton

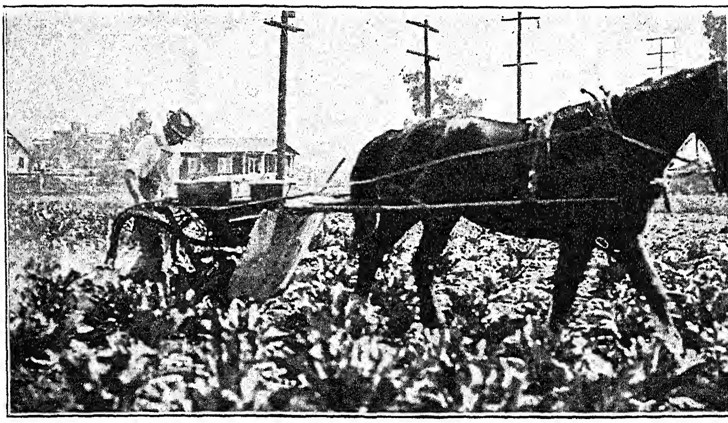


FIG. 30.

at one time, and will cover 15 to 20 acres in one night-operation, cotton dusting being usually carried out at night in order to take advantage of the dew and lack of wind (Fig. 30).

The other type of cotton duster, the two-horse or cart machine, has a capacity of 50 lbs. of dust, but will dust four or more rows at once, and will cover 20 to 30 acres in one night. This duster has two travelling wheels, and the operator rides on the machine. There are three or more nozzles projecting backwards at the rear of the machine, giving an arrangement somewhat similar to that of a spray-boom.

A similar type of traction duster has four flexible metal pipes, each with two branches, a total of eight nozzles in all, and is intended for dusting potatoes or similar field crops. It can be adapted to orchard work by removing the series of pipes and fitting a single discharge pipe and platform to the rear of the machine. A traction

duster, but a different design, is also used for sulphur-dusting hops in England (Fig. 31).

Where a considerable farm acreage or a commercial orchard has to be dusted, a **Power Duster** is advisable. A power duster is mounted upon a light horse-drawn framework, and the different outfits vary from 1 to 5 horse-power. The 5 h.p. machine can dust 6 acres of orchard per hour, and has a hopper capacity of about 100 lbs. of dust.

In the usual type of Orchard Power Duster (Figs. 7, 32) the dust is fed by a revolving brush into the chamber beneath the hopper,

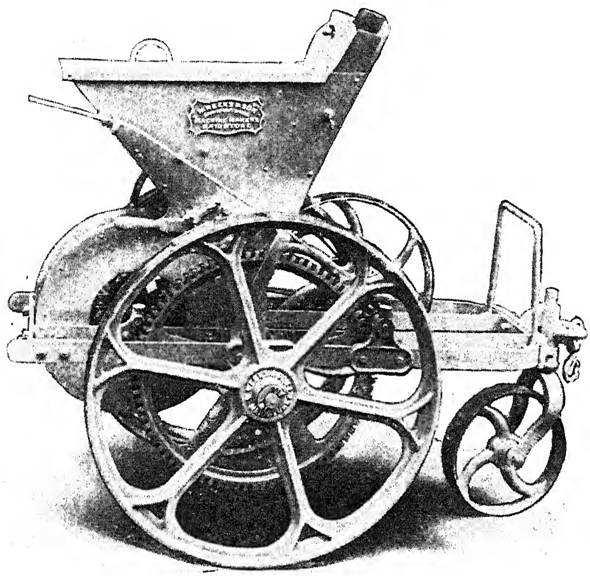


FIG. 31.

and is forced by the air-blast from a rapidly rotating fan into a discharge pipe : a short length of flexible metal hose plus a variable length of galvanised metal piping. The machine requires two men, one to drive, one to operate. The operator stands on the rear platform of the machine, holds up the discharge pipe, and directs the blast of dust from side to side as the machine passes between the rows of trees.

The success of a dusting operation is influenced very largely by weather conditions. Dusting should be carried out when the air is calm, or on two different days when the wind is in opposite directions so that the dust will drift on to the trees. Whereas with liquid spraying there is a tendency to overspray the *lower* parts of the tree, in dusting the lower limbs are more liable to be missed.

In actual practice, however, this is not a serious disadvantage, for the dust floats downwards through the foliage. The great tendency in dry-spraying is to over-dust, since the operator frequently fails to realise that dusting may be quite effective even when the foliage is not visibly covered. Generally speaking, the best time for the operation is early morning or late evening, when the air is quiet and the foliage damp with dew so that the dust will adhere.

In connection with this question of power dusting it should be added that the aeroplane has been used experimentally in dusting operations. A 99 per cent mortality of the Catalpa Sphinx caterpillar is asserted to have been obtained in a Catalpa grove at Troy, Ohio, U.S.A. (Gossard, 1921). A hopper was designed to carry 200 lbs. of calcium arsenate and was attached to the side of the aeroplane, rather lower than and somewhat behind the occupants, so as to avoid inhalation of dust. Dust was fed from the hopper by means of a small reel with spoon-like arms built into the lower part

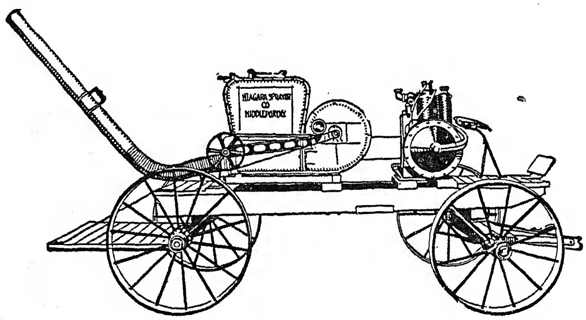


Fig. 32.

of the hopper, and operated by a crank handle turned by the observer in the plane. The aeroplane flew about 50 feet from the trees on the windward side of the grove, and as the wind was blowing strongly it was only necessary to pass once up and down the side of the trees. The dusting is asserted to have been effective for a breadth of 600 feet, and the conclusion drawn is that, with an improved apparatus, as much as 30 acres per minute could be dusted. Apart from the high cost of the apparatus, there is one great drawback to this method, and that is the lack of control over the dust.

In considering the relative merits of dusting and spraying, it must be remembered that the Dusting Method is in a less advanced condition, as regards apparatus and technique, than is the Wet Spraying method, so that it is difficult to arrive at any definite conclusions as regards their rival claims.

The advantages of Dry Spraying over Wet Spraying that are claimed by its advocates are its equivalent efficiency against fungous diseases and biting insects; the smaller risk of foliage damage;

the ease and greater cheapness of application ; economy of material and time, and less expensive machinery.

Although these claims seem to establish an overwhelming case for the use of dusts, it must be pointed out that they are based upon a relatively restricted series of experiments.

The position has been summed up by Whetzel (1920). He considers that up to the present it cannot be said that dusts, as such, are more effective than wet sprays, and that while dusting is quite as effective as wet spraying for fungous diseases and certain biting insects (Codling Moth, for example), its general adoption depends upon the solution of several problems, notably upon the discovery of an efficient contact dust for sucking insects. While these difficulties remain unsolved, the true position of dusting as a general method of Insect Control is not possible to indicate.

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NOTE—(a) *Brackets surrounding a title indicate that it is a translated one.*

(b) *The year of publication of an article is given; the volume-number and page-number are not necessary, since practically all scientific publications are bound in annual volumes and indexed.*

(c) *The following abbreviations require explanation:*

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| *Agric. Jl. S. Afric.* . | *Agricultural Journal of the Union of South Africa.* Pretoria. |
| *Alabama Bull.* . . | *Bulletin of the Alabama Agricultural Experimental Station.* Auburn, Aa. |
| *Ann. App. Biol.* . . | *The Annals of Applied Biology.* London. |
| *Ann. Ent. Soc. Amer.* | *Annals of the Entomological Society of America.* Columbus, Ohio. |
| *Ann. R. Staz. Sperim. Agrum. Fruttic. Acireale.* | *Annali della R. Stazione Sperimentale di Agrumicoltura e Frutticoltura.* Acireale. |
| *Bull. Ent. R.* . . . | *Bulletin of Entomological Research.* London. |
| *Bull. Soc. Étude Vulg. Zool. Agric.* | *Bulletin de la Société d'Étude et de Vulgarisation de la Zoologie agricole.* Bordeaux. |
| *Bull. Soc. Path. Exot.* . | *Bulletin de la Société de Pathologie exotique.* Paris. |
| *California Bull.* . . | *Bulletin of California University Agricultural College.* Berkeley. |
| *Florida Bull.* . . | *Bulletin of the Florida University Agricultural Experimental Station.* Gainesville. |
| *Georgia Bull.* . . | *Bulletin of the Georgia State Board of Entomology.* Atlanta. |
| *Jl. Agric. R.* . . | *The Journal of Agricultural Research.* Wash., D.C. |
| *Jl. Agric. Sci.* . . | *The Journal of Agricultural Science.* Cambridge. |
| *Jl. Bd. Agric.* . . } *Jl. Min. Agric.* . . } | *Journal of the Ministry of Agriculture.* London. |
| *Jl. Econ. Biol.* . . | *The Journal of Economic Biology.* London. |
| *J.E.E.* . . . . | *The Journal of Economic Entomology.* Concord, N.H. |
| *Kansas Bull.* . . | *Bulletin of the Kansas State University.* Lawrence. |
| *Kon. Akad. Wetensk.* . | *Verhandlungen K. Acad. Wetensch.* Amsterdam. |
| *Maryland Bull.* . . | *Bulletin of the Maryland Agricultural College.* College Park. |
| *Michigan Bull.* . . | *Bulletin of Michigan Experimental Station.* East Lansing. |
| *Minnesota Bull.* . . | *Technical Bulletin of the Minnesota Agricultural Experimental Station.* St. Paul. |
| *Montana Bull.* . . | *Bulletin of the Montana Agricultural Experimental Station.* Boseman. |

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| *Monthly Bull. Calif.* . | *Monthly Bulletin of the California State Commission of Horticulture.* Sacramento. |
| *New Hampshire Bull.* . | *Bulletin New Hampshire Agricultural Experimental Station.* Durham. |
| *New Jersey Bull.* . | *Bulletin of the New Jersey Agricultural Experimental Station.* New Brunswick, N.J. |
| *New York Bull.* . . | *Bulletin New York Agricultural Experimental Station.* Geneva, N.Y. |
| *Ohio Bull.* . . . | *Bulletin Ohio Agricultural Experimental Station.* Wooster, Ohio. |
| *Proc. C. Phil. Soc.* . | *Proceedings Cambridge Philosophical Society.* Cambridge, England. |
| *Prog. Agric. Vitic.* . | *Le Progrès Agricole et Viticole.* Montpellier. |
| *R.A.E.* . . . . | *Review of Applied Entomology—(a) Agricultural; (b) Veterinary and Medical.* London. |
| *Science* . . . . | *Science.* New York. |
| *Texas Bull.* . . . | *Bulletin Texas Agricultural Experimental Station.* Brazos. |
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| *Woods Hole Bull.* . | *Biological Bulletin, Marine Biological Laboratory, Woods Hole, Massachusetts.* Lancaster, Pa. |
| *Wyoming Bull.* . . | *Bulletin Wyoming University Agricultural Experimental Station.* Pullman. |
| *Z.A.E.* . . . . | *Zeitschrift für angewandte Entomologie.* Berlin. |
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# GENERAL INDEX

THE END